Use of High-Frequency Imaging Sonar to Estimate Adult Sockeye Salmon Escapement in the Horsefly River, British Columbia

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USE OF HIGH-FREQUENCY IMAGING SONAR TO ESTIMATE ADULT SOCKEYE SALMON ESCAPEMENT IN THE HORSEFLY RIVER, BRITISH COLUMBIA

by

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ABSTRACT

Cronkite, G.M.W., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647: vi + 47 p.

We estimated adult sockeye salmon (*Oncorhynchus nerka*) escapement in the Horsefly River between August 06 and October 09, 2005, using a **d**ual-frequency **id**entification **sona**r (DIDSON) imaging system. This project was the first attempt to integrate the DIDSON system operationally into sockeye salmon assessment programmes in British Columbia. Our primary objectives were:

1. To assess the ability of a high-frequency imaging sonar system deployed in a fixed position immediately upstream of a fish deflection weir to produce escapement estimates of migrating adult salmon returning to the Horsefly River.
2. Determine an effective method for data handling and processing to produce updated estimates of fish passage in a timely manner.
3. Determine if increases in passage rate impact the ability to produce estimates of fish passage within the ensonified region.
4. Implement use of in-river accessory equipment to optimise our ability to detect and enumerate fish passage.
5. Test the effectiveness of solar panels and high amperage batteries to power the acoustic system for extended periods.
6. Train field staff to setup and operate a fixed-location hydroacoustic facility so they can manage future deployments of the DIDSON.

Sockeye salmon returning to the Horsefly River were directed through an 11 m wide opening in a weir installed across the river to allow DIDSON enumeration at high-frequency using manual counting techniques. Maximum sockeye salmon passage observed was approximately 8,000 fish per hour during the season. We estimated total sockeye salmon escapement into the Horsefly River from 06 Aug to 09 Oct. Based on analysis of visual counts and DIDSON-based counts, we found that the DIDSON data were not biased by undetected fish and we conclude that the DIDSON counts of escapement on the Horsefly River are as accurate as counts of migrating fish through an enumeration fence. We compared the distribution of the on-screen DIDSON length measurements (N = 2874) with length measurements from the tagging site of the mark and recapture project located 100 m downstream of the DIDSON site (N = 6260), and found that both measurements were normally distributed with a single mode and that the mean DIDSON length was significantly larger than the mean length of tagged fish ($P<0.05$). Based on these findings, we conclude that the DIDSON and mark-recapture programme provided estimates of escapement for the same population of sockeye salmon, i.e., neither method was biased relative to the other by selective sampling. We expected that the mean length of fish measured

with the DIDSON system would be larger than the mark-recapture programme due to biases in length measurements associated with beam spreading and the downrange resolution of the system as deployed. Empirical corrections for these biases, which are range- and window-length dependent, respectively, can be derived on-site in future applications of the DIDSON technology. We found that overall the DIDSON counts were statistically indistinguishable from comparative visual counts made from the weir, yielding an error of 0% from this source. We made measurements of precision by comparing the manually counted data sets between observers and found the error from this source was ± 6%. The 95% confidence limits (CIs) from temporal sub-sampling ranged from 4 % to 10 % depending on the number of minutes of data used from each hour. Combining the errors from these three known sources gave a total confidence limit of ± 14 % to give a total population estimate of 645,310 ± 90,599. The use of a DIDSON system will allow accurate and cost effective enumeration of sockeye salmon on the Horsefly River for fisheries management purposes.

RESUME

Cronkite, G.M.W., Enzenhofer, H.J., Ridley, T., Holmes, J., Lilja, J., and Benner, K. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647: vi + 47 p.

Nous avons estimé l'échappée de saumons rouges adultes (*Oncorhynchus nerka*) dans la rivière Horsefly entre le 6 août et le 9 octobre 2005 à l'aide d'un système sonar d'identification double fréquence DIDSON. Ce projet était la première tentative visant à intégrer en mode opérationnel le système DIDSON aux programmes d'évaluation du saumon rouge en Colombie-Britannique. Nos premiers objectifs étaient les suivants :

1. Évaluer la capacité d'un système sonar à imagerie haute fréquence installé en position fixe juste en amont d'un déflecteur à poissons de produire des estimations de l'échappée de saumons adultes en migration remontant dans la rivière Horsefly.
2. Trouver une méthode efficace de manutention et de traitement des données pour produire dans un délai court des estimations mises à jour du passage des poissons.
3. Déterminer si une augmentation du taux de passage nuit à la capacité de produire des estimations du passage des poissons dans la zone insonifiée.
4. Procéder à l'utilisation dans le cours d'eau d'équipement accessoire pour optimiser notre capacité de détecter le passage des poissons et de les dénombrer.
5. Tester l'efficacité de panneaux solaires et de batteries à fort ampérage pour faire fonctionner le système acoustique pendant de longues périodes.
6. Former du personnel de terrain à l'installation et à l'exploitation d'un dispositif hydroacoustique fixe pour qu'il soit en mesure de s'occuper des déploiements ultérieurs du système DIDSON.

Les saumons rouges qui reviennent à la Horsefly ont été dirigés vers l'ouverture large de 11 m d'un parc de filet installé en travers de la rivière pour permettre le dénombrement à haute fréquence par le système DIDSON et à l'aide de techniques manuelles de comptage. Le taux maximal de passage observé était d'environ 8 000 poissons à l'heure pendant la saison. Nous avons estimé l'échappée totale de saumons rouges vers la Horsefly entre le 6 août et le 9 octobre. D'après l'analyse des comptages visuels et des dénombrements par le système DIDSON, nous avons trouvé que les données DIDSON n'étaient pas biaisées par des poissons non détectés, et nous en concluons que les dénombrements obtenus par le système DIDSON de l'échappée de la Horsefly sont aussi exacts que les résultats du comptage des poissons en migration à une barrière de dénombrement. Nous avons comparé la distribution des mesures de

barrière de dénombrement. Nous avons comparé la distribution des mesures de longueur sur l'écran du DIDSON (N = 2874) aux mesures obtenues à la station de marquage du projet de marquage-recapture installée à 100 m en aval du système DIDSON (N = 6260), et constaté que dans les deux cas les mesures présentaient une distribution normale à mode unique et que la longueur moyenne obtenue au DIDSON était nettement plus grande que la longueur moyenne des poissons marqués ($P<0,05$). À partir de ces constatations, nous concluons que tant le système DIDSON que le programme de marquage-recapture ont fourni des estimations comparables de l'échappée pour la même population de saumons rouges, c'est-à-dire qu'aucune n'était biaisée par rapport à l'autre en cas d'échantillonnage sélectif. Nous nous attendions à ce que la longueur moyenne des poissons mesurée avec le système DIDSON soit plus grande que celle du programme de marquage-recapture à cause des biais dans les mesures de longueur associées à l'étalement du faisceau et à la faible résolution du système ainsi déployé. Des corrections empiriques de ces biais, qui dépendent respectivement de la portée et de la longueur de la fenêtre, peuvent être calculées sur place pour des applications futures de la technologie DIDSON. Nous avons établi que, dans l'ensemble, les dénombrements DIDSON étaient statistiquement indiscernables de comptages visuels comparatifs effectués dans le parc de pêche, l'erreur étant de 0 % dans ce cas. Nous avons mesuré la précision en comparant les séries de données des comptages manuels entre observateurs et constaté que l'erreur dans ce cas était de ± 6%.Les limites de confiance de 95 % correspondant aux sous-échantillons temporels allaient de 4 % à 10 % selon le nombre de minutes de données utilisées sur chaque heure. La combinaison des erreurs de ces trois sources connues a donné une limite de confiance totale de ± 14 %, ce qui a fourni une estimation de la population totale de 645 310 ± 90 599. L'utilisation du système DIDSON permettra de dénombrer de manière exacte et rentable les saumons rouges de la rivière Horsefly à des fins de gestion des pêches.

1.0 INTRODUCTION

The Horsefly River is a major sockeye salmon (*Oncorhynchus nerka)* producing river in the Fraser River watershed and is characterised by extreme interannual variation in stock abundance on a 4-yr cycle, with spawning ground escapements that can exceed one million fish in a dominant cycle year (Cone 1999). Run sizes of this magnitude support fisheries conducted by First Nations, commercial and recreational sectors. These fisheries are managed to achieve goals for catch allocation and stock-specific spawning escapement, primarily through in-season regulation of harvesting opportunities. This intensive management system means that fishery managers need reliable and timely escapement data for the daily regulation of the fisheries, and to meet annual catch and escapement goals (Woodey, 1987; Noakes et al., 1990).

Mark-recapture programmes (MRP) and visual surveys have traditionally been used to estimate upstream spawning ground escapement in the Fraser River watershed (Woodey 1984). Growing pressures associated with inflationary impacts on the labour and operating costs of MRPs resulted in a search for alternate methods of program delivery that are cost effective and efficient. The dual-frequency identification sonar (DIDSON) was identified as a technology that could maintain assessment coverage and provide accurate and timely data.

We surveyed the major sockeye salmon producing tributary systems in the Fraser River watershed in 2004 to determine where and how the DIDSON system could be deployed for salmon escapement estimation (Holmes et al. 2005). Based on our evaluation in the present study we develop and test the operational methodology to produce an estimate of sockeye salmon escapement in the Horsefly River using the DIDSON acoustic imaging system. Overall the study had the following objectives:

1. To assess the ability of a high-frequency imaging sonar system deployed in a fixed position immediately upstream of a fish deflection weir to produce escapement estimates of migrating adult salmon returning to the Horsefly River.
2. Determine an effective method for data handling and processing to produce updated estimates of fish passage in a timely manner. Methods of processing data files included manual counts using a hand held counter on replay of collected data files, echogram counting and tracking features included within the sonar system software and post processing software that we developed for this purpose.
3. Determine if increases in passage rate impact the ability to produce estimates of fish passage within the ensonified region.
4. Implement use of in-river accessory equipment to optimise our ability to detect and enumerate fish passage.
5. Test the effectiveness of solar panels and high amperage batteries to power the acoustic system for extended periods.

6. Train field personnel to setup and operate a fixed-location hydroacoustic facility so they can manage future deployments of the DIDSON.

2.0 SITE DESCRIPTION

2.1 Study area

The Horsefly River is a large tributary entering the southwest portion of the main arm of Quesnel Lake at Horsefly Bay (Figure 1). The sockeye salmon stock in the river is characterised by interannual variation in abundance on a 4-yr cycle, with the 2005 return as the dominant year in this cycle. We chose the Horsefly River for this study because the expected size of the returning population was deemed to provide an important chance to assess the limitations of the DIDSON system and the software we have developed for assisting in counting under the most extreme conditions of high fish passage rates.

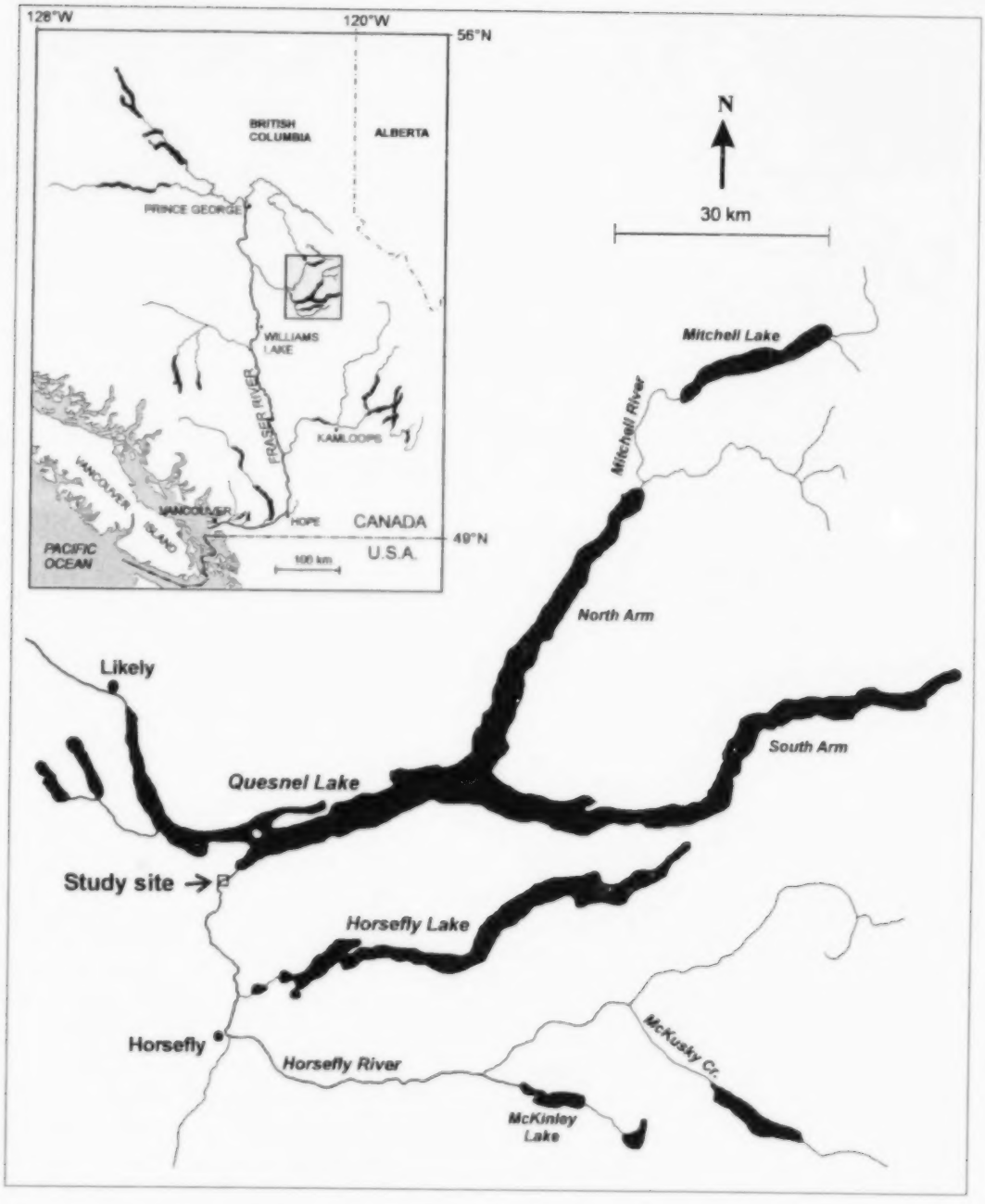

Figure 1. The study area showing the DIDSON site on the Horsefly River in relation to the Fraser River watershed in British Columbia.

The site chosen for hydroacoustic testing on the Horsefly River was approximately 900 m upstream from the river mouth and 100 m upstream of the site surveyed during a feasibility study by Holmes et al. (2005). The DIDSON

site was moved upstream so that it would not interfere with the tagging activities of the mark-recapture programme conducted concurrently at the original site on the Horsefly River. Despite the move, the new acoustic site met the general criteria outlined in Enzenhofer and Cronkite (2000) for site selection, including:

1. A straight channel with laminar flow. Laminar flows produce less acoustic background noise than turbulent flow, resulting in an increased signal-noise-ratio and hence a greater ability to detect fish.
2. A planar bottom, rather than shelved or scalloped. A shelved bank creates riverbed zones that are inaccessible to the acoustic beam.
3. A bottom substrate free of large boulders. Boulders can interfere with the path of the acoustic beam or create turbulent flow.
4. Human activity on the river should be minimal because this may alter fish behaviour and affect the flux estimate (estimate of fish passage through the beam per unit time). This was also a reason why the DIDSON site was moved upstream from the netting efforts of the mark and recapture program.
5. Fish should be actively migrating and not holding or milling. Fish that tend to remain in the sampling area may be counted several times, which would lead to overestimates of flux. However, with the DIDSON imaging sonar system these holding fish can be identified and separated from the upstream flux. The occurrence of these holding fish increases the amount of time needed to process the collected data files.

The Horsefly River is 57 m wide at the acoustic site used in 2005 and average discharge ranged from 5.17 $m^3 s^{-1}$ to 50.0 $m^3 s^{-1}$ during the 2004 migration period (Water Survey of Canada website accessed 23 Dec 2005). The majority of water flow and hence fish passage is funnelled through a relatively deep 15 m wide channel along the left-bank (Photo 1 and Figure 2) (left- and right-banks are identified when facing downstream). This channel was created by a gravel bar 15 m offshore that extended 100 m downstream and continued 30 m upstream of the acoustic site (Photo 2). The gravel bar extended upstream of the site to where the river displayed a shallow and flat cross-section. We used 7.4 m of sectional fish deflection weir on the left-bank and 37 m of sectional weir on the right-bank to cover the wetted width of the river cross-section (Figure 2; Enzenhofer et al. 2005). A 3 m section of DuPont Vexar™ fencing, attached to angle iron driven into the substrate, was added to the end of the right-bank weir creating an 11 m opening between the two weirs.

Photo 1. Cross-sectional view of the DIDSON hydroacoustic site on the Horsefly River. This downstream view shows the 7.4 m sectional fish deflection weir on the left-bank and a 37 m sectional weir on the right-bank. Active fish migration occurs in the faster flowing channel near the left-bank, between the two weirs. Photo taken by Juha Lilja on September 17, 2005.

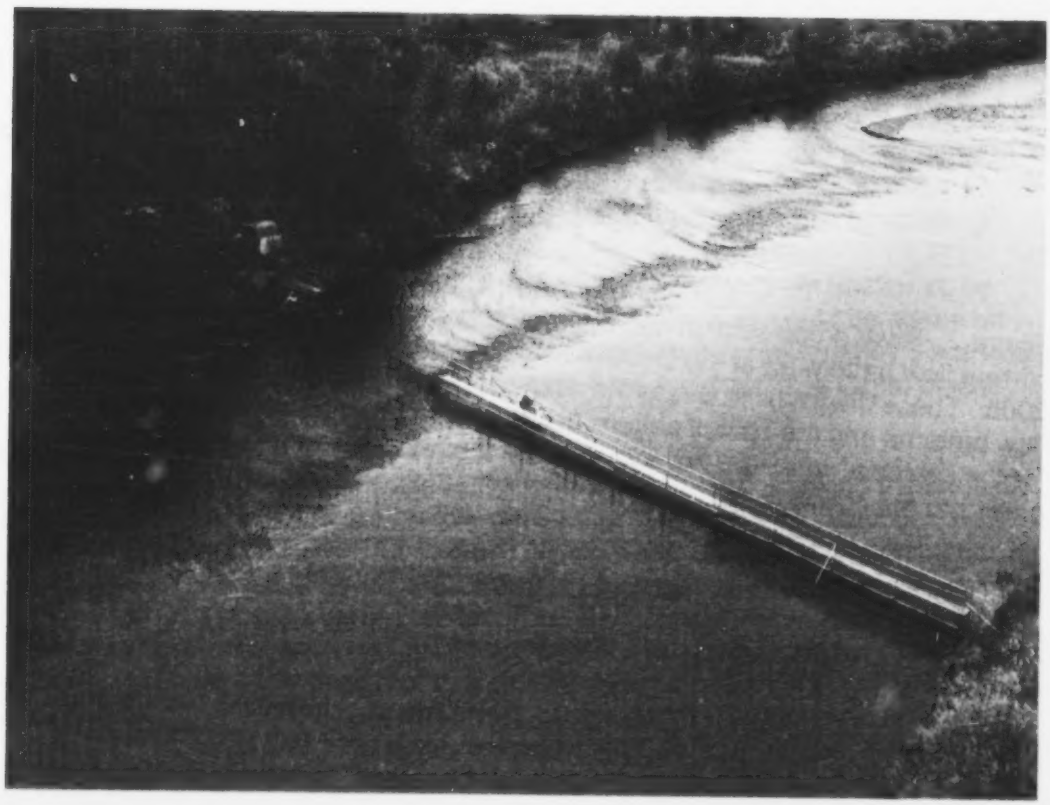

Photo 2. Aerial view of the hydroacoustic enumeration site on the Horsefly River. Note the extensive gravel bar running parallel to the left-bank creating a natural channel for fish passage between the two sectional fish deflection weirs. The river flow is from bottom left to top right in this photograph. Photo taken by Rob Dolighan on September 25, 2005.

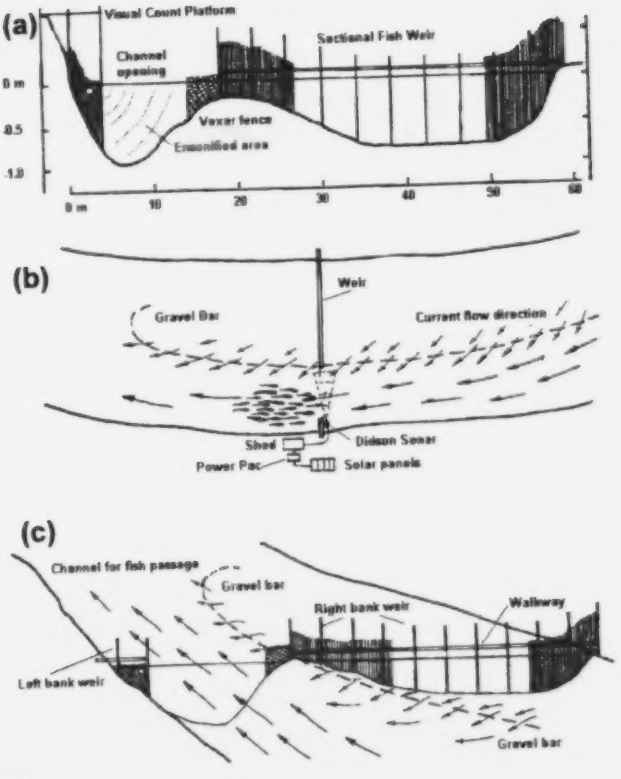

Figure 2. River cross-section and measured bottom profile (a), plan view (b) and current flow pattern (c) at the DIDSON acoustic site on the Horsefly River in 2005. These diagrams illustrate the equipment configuration relative to water flow patterns and the spatial pattern of fish movement upstream. The handrails for the sectional weirs are not shown. Note that the vertical conduit dowels and poles are not drawn to scale.

3.0 MATERIALS AND METHODS

3.1 Acoustic Data Collection

We used a standard DIDSON acoustic imaging system in high frequency mode (1.8 MHz) for data collection. In this mode the system utilises multiple sound beams focused through a moveable lens to produce near video quality images comprised of frames produced by 96 beams. A frame (image) is constructed in sequence and consists of 8 sets of 12 beams fired simultaneously (Belcher et al. 2001, Sound Metrics Corporation 2005). Each beam is 0.3° wide and together produce a nominal field of view 29° horizontally and 12° vertically. The maximum attainable range with the high frequency setting is 15 m, using a window length of 10 m and a start range of 5 m. We operated the DIDSON with

a 10 m window length (0.83 m to 10.83 m), a frame rate of 5 frames per second and the maximum receiver gain of 40 dB. With these settings, approximately 14.25 megabytes per minute were recorded, resulting in data files of 285 megabytes per 20 minute time period. The DIDSON system was programmed to create new files (time and date stamped) beginning at the top of the hour for a specified period. Files of 60 (Aug. 6-10, N = 68), 30 (Aug. 8-12, N = 51), 20 (Aug. 20 to Oct. 9, N = 1050) and 10 minutes (Aug. 12-20, N = 359) duration were recorded. All digital data were recorded and post-processing of fish counts was made using Version 4.51 of the DIDSON operating system software (Sound Metrics Corporation 2005). Data was backed up to two external hard drives of 250 gigabytes and one of 300 gigabytes in size, creating two copies of the data, which was sufficient redundancy for archiving and storage purposes.

The DIDSON system was deployed on an adjustable pole mount attached to a modified step-ladder anchored to the riverbed (Enzenhofer and Cronkite 2005) approximately 1.5 m from the left-bank shore. The adjustable pole mount provides precise manual control of the depth, bearing, roll angle and tilt angle of an attached transducer. A stabilising bracket between the pole mount and the ladder prevented movement of the transducer in the fast current, which could result in blurred images. The system was positioned so that the lens was 10 to12 cm below the water surface and the transducer was aimed at -6° angle relative to the water surface and perpendicular to the shoreline and water flow. Using this aim, the DIDSON beams ensonified the entire 11-m weir opening illustrated in the cross-river bottom profile in Figure 2 (a). The upstream/downstream boundaries of detection were physically confirmed by observing the limits at which a person standing in the river could be observed with the DIDSON system. The vertical boundaries were confirmed by observing the image from the substrate and the image from a salmon size target placed near the surface, at various ranges from the DIDSON system.

Topside equipment such as the laptop computer controlling the acoustic system and the DIDSON switch box were housed in a portable Rubbermaid storage shed Model RHP3752 (2.6 m^3) on top of the left bank. All electronic components and the acoustic system were powered by 12V battery power and a 700 W (12 VDC to 120 VAC) inverter. The 2005 season was the first test of a power system developed for remote applications in which line power is not readily available. The design of this system uses solar power to charge two parallel banks of two 6V batteries (four batteries in total) connected in series to produce 12V power. We used Trojan Model J305 H 6V batteries, which provide 335 ampere hours (AH) (this is a 20 hour rating) of power and housed the batteries in a stainless steel vented box. The stainless steel battery box also housed the DC-AC inverter and battery charging controls. The batteries were charged using four (4) 85 W solar panels (Sharp NE-80EJE) installed in a stand attached to an extendable pole (maximum height 4 m). The solar panel bed was designed to be rotated 360° horizontally and 45° vertically in 5° increments in order to achieve the most efficient incident angle with the sun. A 2 kW generator

provided additional charging capacity and was used during periods of high load associated with the operation of multiple computers for data analysis.

3.2 DIDSON Fish Counting

All DIDSON data files were counted manually using a hand held counter (tally whacker) and the numbers of upstream and downstream fish were recorded on a spreadsheet. The spreadsheet calculated the net upstream count and the expansions for the unsampled portions of the hour. Most data files were 20 minutes in length, however only 10 minutes were counted from some of the files collected during periods of high passage rates to reduce the time required to process these files. If files were counted more than once by different observers, then the average count was used in the spreadsheet to calculate the hourly net upstream passage. The spreadsheet was designed to plot daily cumulative run-timing curves along with per cent downstream moving fish, to allow the assessment of run strength and timing. The visual count data were also recorded in the spreadsheet for later analyses. Notes were kept of unusual events or items that needed later attention, such as adjustments to percent downstream to take into account the moribund post-spawning sockeye salmon moving past the acoustic site.

The DIDSON files were more difficult to count manually during periods of high passage rates because of the behaviour of the fish. We found it practical to count the files in stages. First, we would magnify (zoom) the first 4.5 m range (short range) and in combination with background subtraction we would count the data set at a frame rate that was comfortable for the observer. Fish crossing the line between range strata were noted and fish were counted in the short range if the last half of its track as it left the field of view was in the short range. Fish that left the short range counting window before leaving the field of view were counted in the long range window. Second, we would perform the same procedure to count the upstream moving fish at longer range, by magnifying the range from 4.5 m to the end of the 10 m window. This range stratification allowed us to more easily count the fish as the images were larger and therefore the observer can more easily observe the full range without missing fish at a particular range. For example, we found that many fish would travel very close to the transducer but there was also another grouping at approximately 7 m range, requiring constant, fatiguing, eye movement to follow both groupings. After the upstream fish were counted, the downstream migrants were counted over the entire 10 m range with the background subtraction turned off. We used this procedure for downstream migrants because far fewer fish moved downstream than upstream and because these downstream fish typically moved very fast through the beam, resulting in low intensity, unresolved images.

The display images used for upstream and downstream counts were corrected for sound transmission loss to increase the detectability of fish over the

10-m range window used. This correction equalises the intensity of the images of the long-range and short-range fish. Without transmission loss correction, fish at short-ranges from the transducer appear much brighter than fish at longer ranges. At present, there is no consensus concerning the appropriate transmission loss correction that should be applied to an imaging system; we used 30 log R (where R = range, m) because this seemed to provide the best clarity for all observers. The application of transmission loss to the data files initially decreases the perceived brightness of the images but this can be adjusted by the observer using the intensity control slide bar in the playback software.

All data files were processed using the tools and software package provided by the manufacturer, Sound Metrics Corporation, and described in operation Manual Version 4.51.02. We used the following features of this software package during the study:

- Playback frame rate: Acoustic data files could be played back at an increased or decreased frame rate from that used to collect the data. Choice of frame rate was dependent on the fish passage rate and comfort zone of the observer to accurately count the fish.
- Zoom: This feature allowed us to magnify the image from selected range boundaries during playback when fish passage rate was high and expand the selected range over the entire DIDSON screen. For example, one playback with a range bin of 0.83 m to 4.5 m and then a second playback from 4.5 m to 10.83 m were used to cover the entire range from 0.83 m to 10.83 m. The zoom feature was also used to isolate a single image and expand it on-screen when measuring tools were used.
- Background subtraction: This feature will remove the static portion of the acoustic image, showing only moving objects such as fish. Use of background subtraction was left to the discretion of the observer but was most effective when used in conjunction with the zoom feature.
- Correct for transmission loss: Corrects the displayed image for acoustic transmission loss with range, increasing the detectability of fish images at farther range.
- Echogram: Allows the user to display a recorded data file similar to a chart recorder to display averaged beams in the center of the sonar image over time. This feature was effective when low numbers of fish images were recorded in a file and the echogram could be scrolled through to an event, the event marked, and then played back as a DIDSON image for identification.
- Measure: Allows the user to measure the width, height and range in meters of a selected image.
- Mark fish: Allows the user to zoom in on an image, mark its range, measure the length and automatically enter the data to a fish count file. This feature was used to compare the fish lengths measured at the tagging site and the fish lengths measured with the DIDSON for a similar time period.

- Rectangular Display: Allows the conical beam projection to be displayed as rectangular. This display mode was used according to user preference at higher passage rates. The lengthening effect of this view mode on the fish images provided a slightly longer time for the viewer to detect the fish especially when fish were swimming close to the transducer.

3.3 Downstream moving fish and the flux model

The hourly count data obtained with the DIDSON system were used in a simple model (Xie et al. 2002) to estimate the net upstream flux (fish per unit time) of salmon passing through the acoustic site. This model is:

$$N = U - D \quad (1)$$

where N = the net upstream flux, U = the upstream actively migrating fish and D = the downstream actively migrating fish. For resident species not engaged in migration, the model assumes that there is an equal probability of upstream or downstream movement past the site, and therefore $U = D$. Milling fish can also be accounted for in this model, provided these fish eventually move upstream through the acoustic beam. Spawned-out moribund fish have to be removed from the downstream estimate since the model relates only to actively migrating fish, and moribund fish would have been included in the spawning population as upstream fish. Summed over 24 hours, this model produces daily escapement estimates that are compiled to estimate the total spawning population entering a river.

Resident species as large as sockeye salmon are rare in the Horsefly River but when observed, were usually large rainbow trout (*O. mykiss*). We assume that these resident fish engaged in opportunistic behaviours but not in migratory activity, have an equal probability of moving in the upstream or downstream direction through the acoustic site. On a few occasions we visually noted this behaviour amongst rainbow trout and amongst the smaller species such as suckers (*Catostomus* sp.) and juvenile Chinook salmon (*O. tshawytscha*). Most resident species were excluded from the DIDSON counts due to their smaller size and the lack of directed upstream migration.

3.4 Visual Counts

We collected visual counts and recorded and counted simultaneous DIDSON acoustic files of fish passage during daylight hours throughout the study period. All visual counts were made by an observer standing at the end of the left- bank weir (Figure 2) wearing Polaroid sunglasses to reduce glare at the water surface. Visual data collection was synchronised with the DIDSON data collection by radio notification to the visual counter of the start and end of the

concurrent DIDSON file. Acoustic files were counted directly from the DIDSON screen during recording, or were post-processed in playback mode. Both the visual counter and the DIDSON counter recorded the number of fish moving upstream and the number moving downstream during the counting event. In addition, the file length (10 or 20 min.) and visibility conditions for the visual counts (categorised as poor, fair or good) were recorded (Table 1).

Visual downstream counts were made in order to produce the net upstream passage for each data set as per the flux model (Section 3.3). Later in the season, the presence of moribund fish moving downstream was recorded and these data were used to correct the estimates of downstream fish so that they reflected only actively migrating fish. The moribund fish were passively migrating downstream and were not subtracted from the upstream flux because they were previously counted on their upstream migration to the spawning grounds. Visual counts of these post-spawners had to be made as they could not be distinguished from milling pre-spawners in the DIDSON images.

Between September 17 and September 30 we found that low numbers of fish were observed moving upstream below the right-bank weir, which appeared to stop upstream movement. We made small openings in the right-bank weir and counted these fish through manually when we noted this behaviour. The number of fish moving upstream past our acoustic site in this manner was minimal relative to estimates of daily passage, with a highest daily count through the right-bank weir of 145 sockeye salmon. Typically, the weir was opened for these fish to pass after the daily removal of debris and carcasses from the upstream side of the fence was completed, i.e., around mid-morning.

The collection and analysis of concurrent visual and DIDSON count data is part of the data quality assurance procedures for DIDSON enumeration sites. The correct implementation and use of these procedures is important for three reasons. First, although the accuracy of count data from a DIDSON system is known (see Holmes et al. 2006), this accuracy can only be achieved if the protocol used to collect these data is not biased. Therefore, the comparison of the visual and DIDSON count data is used to assess the performance of our data collection protocol by detecting potential bias in the counts associated with fish moving through acoustic blind zones unobserved by the DIDSON system. A line fitted to a plot of these data with a slope of 1.0 and passing through the origin ($y=x$ line) supports a conclusion that the DIDSON data are not biased and that our data collection protocol is correct. Second, these data are used to detect and correct for bias in DIDSON counts related to upstream movements of other salmon species or salmon-sized non-target fish species (e.g., rainbow trout) because we do not have a robust and reliable protocol for species identification with the DIDSON system unless there are clear and consistent size or behavioural differences between species. Third, the visual data were used to quantify the downstream movement of moribund sockeye during the latter half of

the migration period because at present, we do not have any method for accomplishing this task from the DIDSON images.

3.5 Data Analysis

Fish count data were analysed on a data file basis where a data file was 10, 20, 30, and in some cases 60 minutes in length. The fish counts from the visual and DIDSON data consisted of a series of paired values that would be expected to exhibit a linear trend when plotted (Holmes et al, 2006). We used an errors-in-variables approach to compare these data because both methods used at the site were subject to error stemming from biological and measurement variability (Schnute et al, 1990). We fit standard regressions to DIDSON counts vs. visual counts and visual counts vs. DIDSON counts. These regressions represent two extremes and bound the true relationship, which we infer lies between these extremes. Three possible outcomes for describing the true relationship between the visual and DIDSON count data are foreseeable. First, the true relationship is coincident with a line with slope of 1.0 that passes through the origin, i.e. the y = x line, which we interpret as meaning that both counting methods agree. Second, the true relationship is parallel to but not coincident with the y = x line, i.e. the intercepts differ significantly from 0, and is consistent with an interpretation of constant bias (or offset) in the count data. Third, the true relationship is not parallel to the y = x line, which is also consistent with a conclusion that the counting data are biased, but the bias varies systematically as the counts increase. We bootstrapped 1000 replicates and plotted the distributions of possible slopes and Y-intercepts with their 95% confidence intervals. We then determined from these distributions if the 95% confidence intervals of slope and intercept included 1 and 0 respectively.

Precision refers to the repeatability of a count between different individuals for the same data file. We assessed the precision of the DIDSON counts among individuals using the coefficient of variation (CV) and average percent error (APE) as was done by Holmes et al. (2006) and is widely used to report the precision of the fish ageing process, where:

$$CV = \sqrt{\frac{\sum_{i=1}^{R}(X_{ij} - \bar{X}_j)^2}{\bar{X}_j^{\,2}}} \quad \text{x} \quad 100 \tag{2}$$

$$APE = \frac{1}{N}\sum_{j=1}^{N}\left[\frac{1}{R}\sum_{i=1}^{R}\frac{\left|X_{ij} - \bar{X}_j\right|}{\bar{X}_j}\right] \times 100 \tag{3}$$

and N is the number of events counted by R observers, Xij is the i^{th} count of the j^{th} event and Xj is the average count of the j^{th} event. APE as specified above is

an index of the repeatability of counts across the entire dataset, whereas CV is a measure of the variability in counts of a particular file among observers.

The method of successive difference was used to estimate the variance caused by temporal expansion from 10 minute, 20 minute and 30 minute counts into hourly estimates (Wolter, 1985; Eggers et al., 1995). The following systematic sample-variance estimator was used:

$$Var(\hat{Y}) = N^2\left(\frac{1-f}{n}\right)\sum_{i=2}^{N}\frac{(y_i - y_{i-1})^2}{2(N-1)} \qquad (4)$$

where y_i is the estimated number of fish passing the sampling site during hour i, N is the total number of one-hour sample periods, n is the total sampled time in hours, and f is the sample fraction (n/N). Variances were estimated separately for continuous time periods which have a constant sample fraction. In addition, the variance from multiple observers counting the files (APE) was calculated as in equation (3) above. Thus, the estimate of total variance for our upstream escapement estimate is the sum of these variance components and expressed as the standard deviation for the total count ($SD_{TotalCount}$) is:

$$SD_{TotalCount} = \sqrt{Var(\hat{Y}_{10-\min}) + Var(\hat{Y}_{20-\min}) + Var(\hat{Y}_{30-\min}) + Var(\hat{Y}_{APE})} \qquad (5)$$

The resulting standard deviation is in numbers of fish for the total count and the 95% confidence interval, which we report, is calculated by multiplying the standard deviation by ± 1.96 for normally distributed data (Pagano, 1981).

3.6 Sub-sampling analysis

The estimate of total passage based on the first 10 minute count series (X_i) and the second 10 minute series (Y_i) was analysed separately in order to test the hypothesis that both counts will lead to an equal estimate of the spawning population. In addition, the estimate of the spawning population was calculated from whole 20 minute count series (Z_i). The method of successive difference was used to estimate a variance caused by temporal expansion from 10 minute or 20 minute counts into hourly estimates (Wolter, 1985; Eggers et al., 1995). In this method, the variance can be estimated strictly from adjoining pairs of counts using the systematic sample-variance estimator presented in Equation 4. When the total number of one-hour sample periods (N) and unit variance (behind $\sum$) are known, the confidence intervals for the total population estimate can be calculated for various sampling rates.

3.7 Fish Length Measurements

The DIDSON software has several tools to assist the user in measuring and recording the lengths of selected fish. We compared lengths of sockeye salmon measured from the DIDSON screen with the lengths measured by the tagging crew at the tagging site downstream of our acoustic site. The tag crew recorded the end time for the set, the number of fish caught, and the sex, fork length to the nearest 0.1 cm, and Peterson disk tag number of each fish tagged. We selected DIDSON files for time periods as close as possible to the ends of the sets and the equivalent numbers of fish were randomly selected and measured for length up to a maximum of 100 sockeye salmon per day. The resolution of the DIDSON system is not sufficient to permit the identification of tagged fish in the images so we assume that there was an equal probability that tagged and untagged fish were measured in the DIDSON images.

Fish images at 1-6 m range in the DIDSON files were randomly selected for length measurements. Only fish which produced a clear image and were perpendicular to the transducer (to reduce bias in length measurements associated with fish angle) were used in the data set. The majority of fish that were selected were travelling in the 4.0 to 6.0 m range from the transducer because we found that these images were clearer than fish images at farther ranges (6.0 to 11.0 m), which tended to be blurred when paused for measuring. Furthermore, fish very close to the transducer (e.g., within 1-2 m) were often only in 1 or 2 frames and so were not selected because there were few frames in which these fish were wholly visible and oriented correctly for measurement. The following procedure was used to compile fish length measurements from DIDSON files:

1. Files were played back with the background subtraction enabled to provide an image of the moving fish and to remove stationary objects.
2. Once a fish was selected the file was paused (freeze-frame) and a box was drawn around the image to allow magnification of the image.
3. Frames which contained the fish image were stepped through one at a time until the clearest image was attained. Fish that did not produce an entirely visible image where excluded from the data set.
4. The Mark Fish option was enabled to provide a cursor with which the fish length could be measured, its range marked and then entered to a fish count file.

4.0 RESULTS

4.1 Estimate of sockeye salmon population

Figures 3 and 4 display the daily and cumulative sockeye salmon escapement for the Horsefly River in 2005. The 2005 sockeye salmon migration into the Horsefly River began August 06 and finished October 09. The daily escapement plot displays multi-modal run timing with a maximum daily net upstream escapement estimate of 64,488 sockeye salmon on September 13, 2005. The halfway point in the 2005 run, when 50% of the total estimate had passed the DIDSON site, occurred on September 14 (Fig. 4) and the total escapement point estimate for the season was 645,310 sockeye salmon.

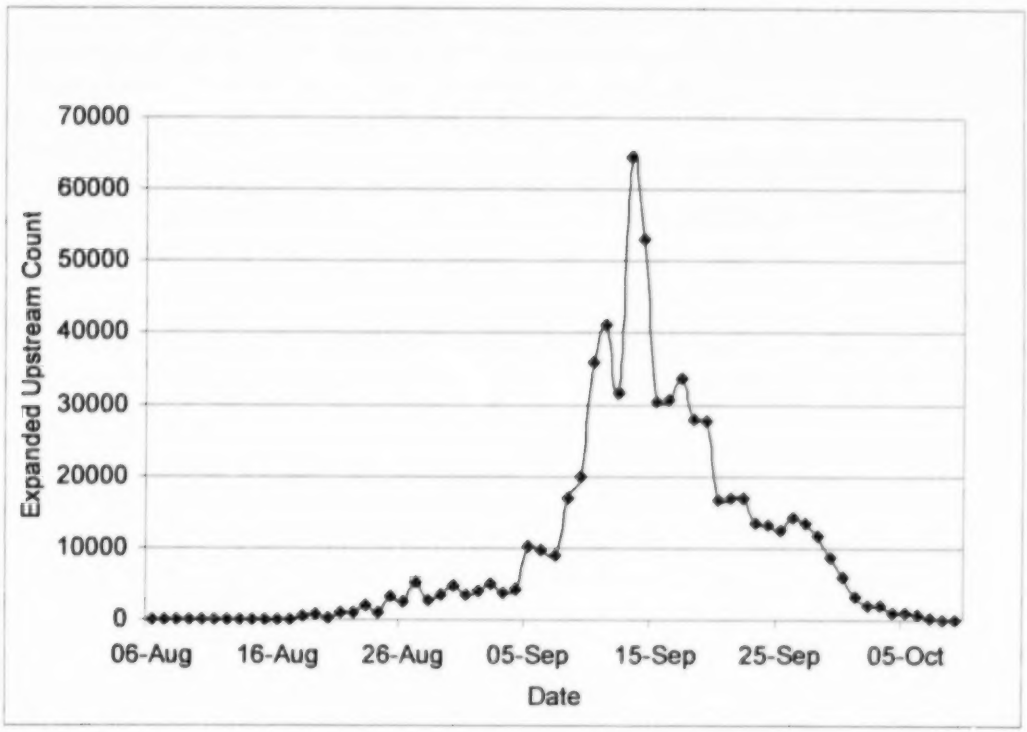

Figure 3. Daily net upstream sockeye salmon migration past the DIDSON site on the Horsefly River in 2005.

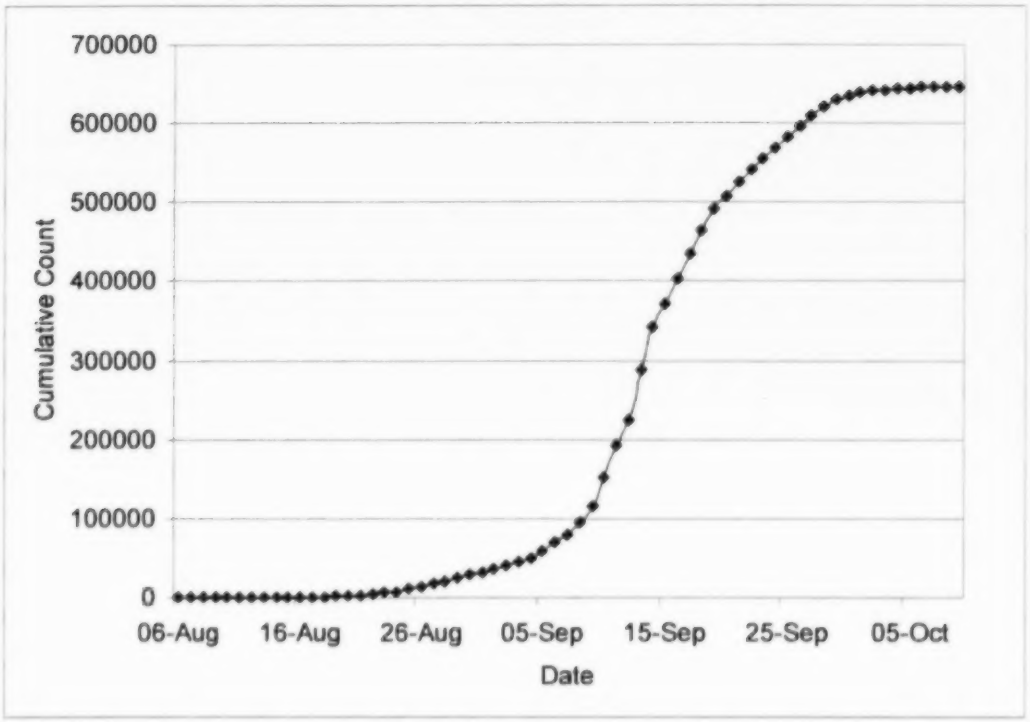

Figure 4. Cumulative daily net upstream sockeye salmon migration past the DIDSON site on the Horsefly River in 2005.

We estimated a 95% confidence interval of ± 90,599 (± 14%) around our point estimate of sockeye salmon escapement in the Horsefly River. The width of this interval reflects errors associated with 1) counting the DIDSON data sets (accuracy), 2) the repeatability of counts between different individuals for the same data sets (precision), and 3) temporal sub-sampling (representativeness of the sampling). The error in counting the DIDSON data sets is discussed in section 4.2 and can be considered overall to be zero for this population estimate as the DIDSON data are not biased by fish moving past the site undetected, so there is no error associated with non-representative sampling. The repeatability of counts using the APE is discussed in section 4.3 and contributed an overall error of ±6% and the temporal sub-sampling contributed an overall error of between ±0% when the full hour was counted, to ±10% when 10 minutes were counted. The error for each data set was calculated according to the length in minutes of the counted portion of the hour. Most of the data sets collected were 20 minutes in length, although a small number were 10, 30 and 60 minutes in length. Counting the full 20 minutes gives a ±5% error, but some of the data sets during the high density migration were counted for 10 minutes giving a ±10% error, as discussed in section 4.4. When all of the identified errors were combined according to equation 5, we arrived at a total error of ±14%.

Figure 5 displays the daily percentage of downstream migrating sockeye salmon from the DIDSON data for the entire run superimposed over the daily estimates. Early in the migration period, the proportion of downstream travelling sockeye salmon was relatively high, varying between 20 and 40% of all fish counted. This high level of downstream movement was related in part to milling behaviour of early migrants (travel upstream and downstream, possibly several times), which were moving primarily during the night, past the acoustic site. During the middle part of the migration, when the bulk of the fish passed the acoustic site and migration was occurring at all hours of the day, the proportion of downstream moving fish declined to 8-10%, reflecting the more directed upstream travel, especially during the days of high migration. In the later part of the season there was a sharp rise in the proportion of downstream fish associated with some milling pre-spawners and with an increasing number of moribund post-spawners that were merely drifting with the river current. These moribund fish were not included in the downstream counts used to estimate net upstream flux. This sharp increase in the number of downstream fish is consistent with increased die-off of the spawning population, but in 2005 this increase may have been amplified by late season increases in water level due to rainfall, which flushed more of the post-spawners down the river. The late season divergence of the net upstream flux and downstream proportion in Figure 5 may be a useful way to characterise the end of the migration period.

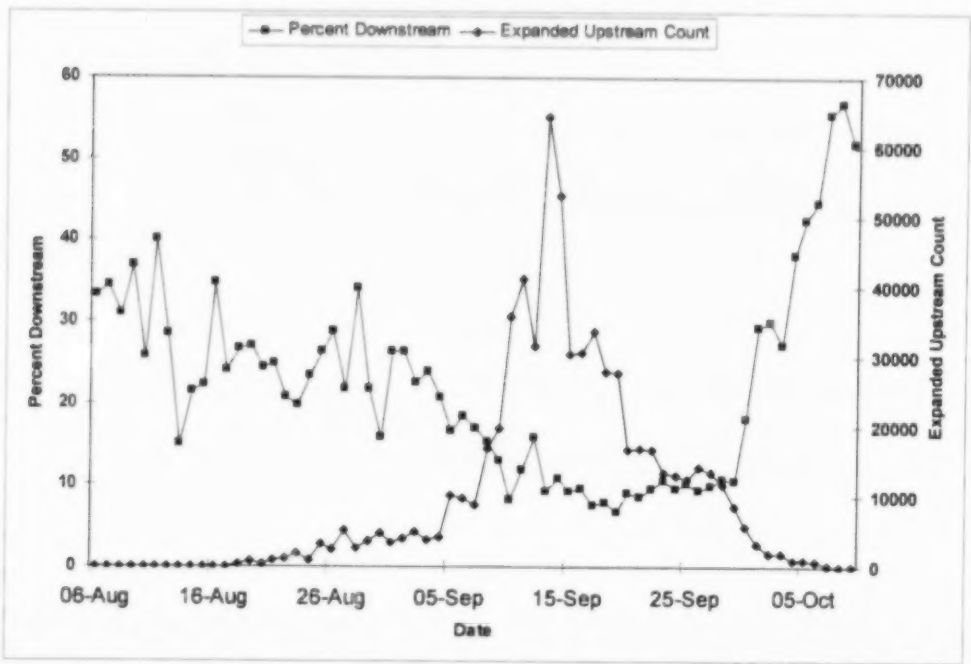

Figure 5. Plot displaying the daily percentage of downstream migrating sockeye salmon (square markers) superimposed over the daily upstream count (diamond markers).

Daily run timing based on the 5 day averages for three periods, August 19 to 23 (early season), September 11 to 15 (mid-season/run peak) and September 29 to October 03 (late season), is shown in Figure 6. In the early season there was little or no migration past the DIDSON site between 07:00 and 21:00, corresponding to daylight hours. Migration began after dusk and continued on until near dawn. This pattern was evident as late as September 05 although the low passage rate time decreased from 15 hours in the early season to about 6 hours, generally between the hours of 10:00 to 15:00. As the sockeye salmon passage rate increased during mid-season, the migration occurred throughout the day and did not seem to be correlated to any particular condition or event. Daily peaks in migration tended to occur around 18:00 in mid-season, but the timing of this peak was not consistent on a weekly basis. In the late season, sockeye salmon migration occurred throughout the 24 hour period but there was a tendency for higher counts during daylight hours and lower counts in the hours of darkness after sunset but prior to midnight.

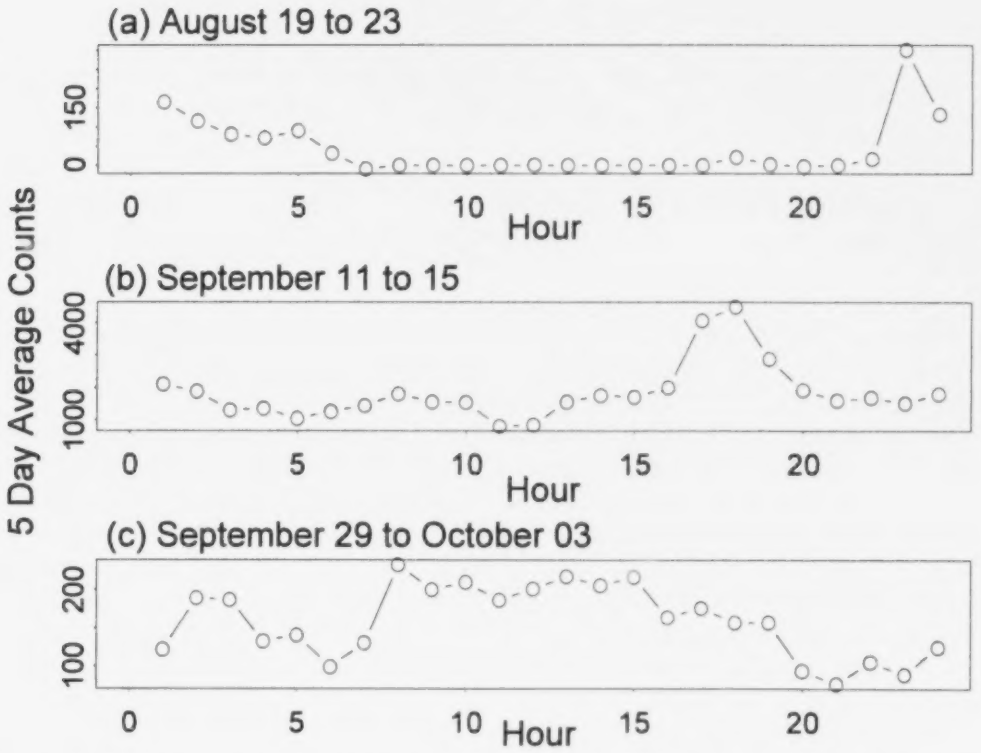

Figure 6. 5-day average temporal migration patterns for sockeye salmon at the Horsefly site for (a) early season, (b) mid-season and (c) late season. Note that the scale of the Y-axis differs among plots. For clarity, measures of variance associated with these average values are not shown.

The horizontal distribution of the migrating sockeye salmon relative to the DIDSON transducer, which covered the whole opening between the ends of the left-bank and right-bank weirs at the Horsefly site, changed as the season progressed (Figure 7). In the early season (August 19 to 23) the fish tended to pass through the acoustic site at 4 to 8.5 m range from the transducer, which corresponded to the deepest part of the channel or thalweg. As the season progressed to the mid-season peak of the run (September 11 to 15), and the abundance of sockeye salmon increased, the distribution of migrating fish became more uniform across the channel, but with a tendency for travel closer to the left-bank weir and therefore close to the DIDSON system. In the late-season period (September 29 to October 03), the majority of fish moving upstream did so on the left-bank side of the thalweg probably due to the presence of spawning fish on the right side of the thalweg at 6 to 11 m range. These spawning pairs were aggressive and usually forced migrants closer in range to the DIDSON system.

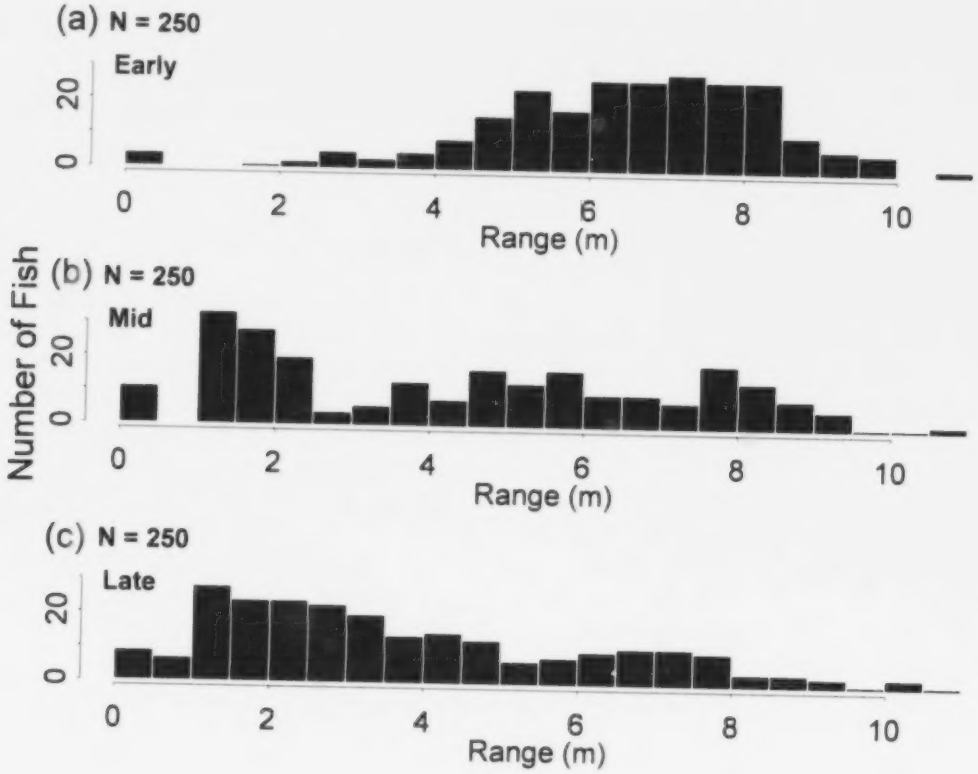

Figure 7. Histograms showing the horizontal distribution of migrating sockeye salmon relative to the DIDSON transducer during the (a) early, (b) middle, and (c) late season as defined in Figure 6. Each plot is for a randomly selected sample of 250 sockeye salmon from the DIDSON data for each time period.

4.2 DIDSON counts compared to visual counts

Net upstream passage rates estimated from the visual count data ranged from 0 to 5,160 fish/hr while net passage rates estimated from concurrent DIDSON counts ranged from 0 to 7,332 fish/hr (Figure 8). The regressions defining the lower and upper bounds fitted to the count data, which are two measures of the same phenomenon are:

LB: Ln DIDSON = -0.1803 + 1.0185 x Ln Visual, R^2 = 0.98, N = 104, P = 0

UB: Ln DIDSON = 0.2746 + 0.9615 x Ln Visual, R^2 = 0.98, N = 104, P = 0

The solid lines on Figure 8 represent the regressions assuming that all of the error is in the visual counts (red) and assuming that all of the error is in the DIDSON counts (black). The true relationship lies somewhere between these two lines and in this case is nearly superimposed on the one-to-one line (dashed line). The bootstrapped 95% confidence intervals around the slopes of these lines (Figure 9) and the intercepts (Figure 10) include values of 1.0 and 0 respectively, from which we infer that the visual counts and the DIDSON counts are equivalent measures of the same phenomenon and that we were not missing fish through non-detection in the DIDSON beam.

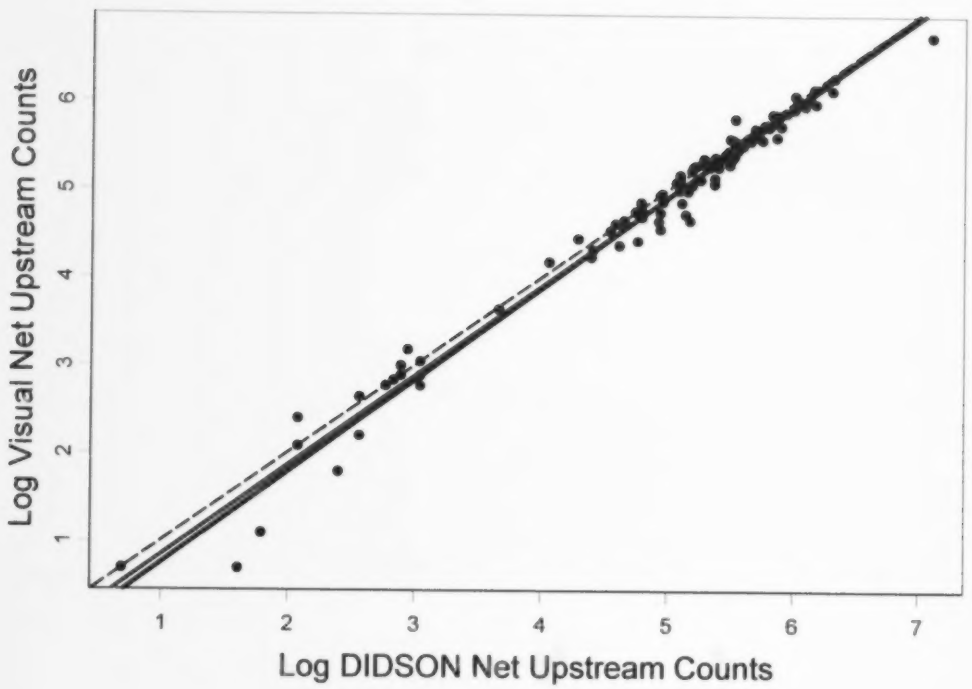

Figure 8. The natural log relationship between the visual and DIDSON counts (counts for 10 and 20 minute files) for net upstream migrating sockeye salmon. The dashed line is the one-to-one line and the red line represents the regression line assuming that all of the error is in the visual count and the black line represents the regression line assuming all of the error is in the DIDSON count.

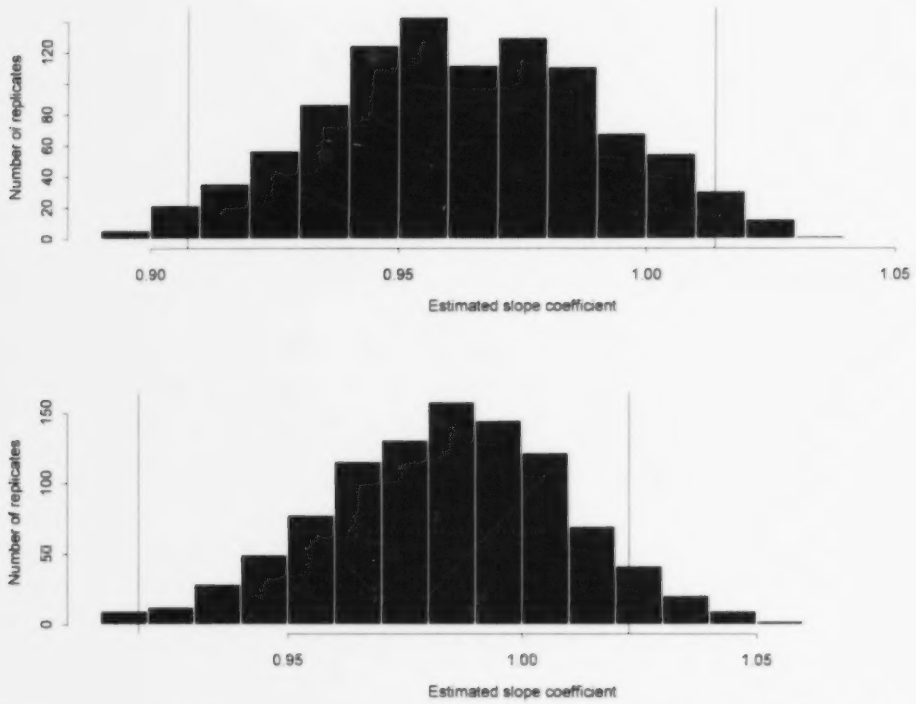

Figure 9. Distribution of boot-strapped estimates of slope coefficients for DIDSON vs. visual and visual vs. DIDSON regressions in Figure 8, based on 1000 replicates. The top histogram assumes that all of the error is in the DIDSON counts and the bottom histogram assumes that all the error is in the visual counts. The vertical lines represent the 95% confidence intervals.

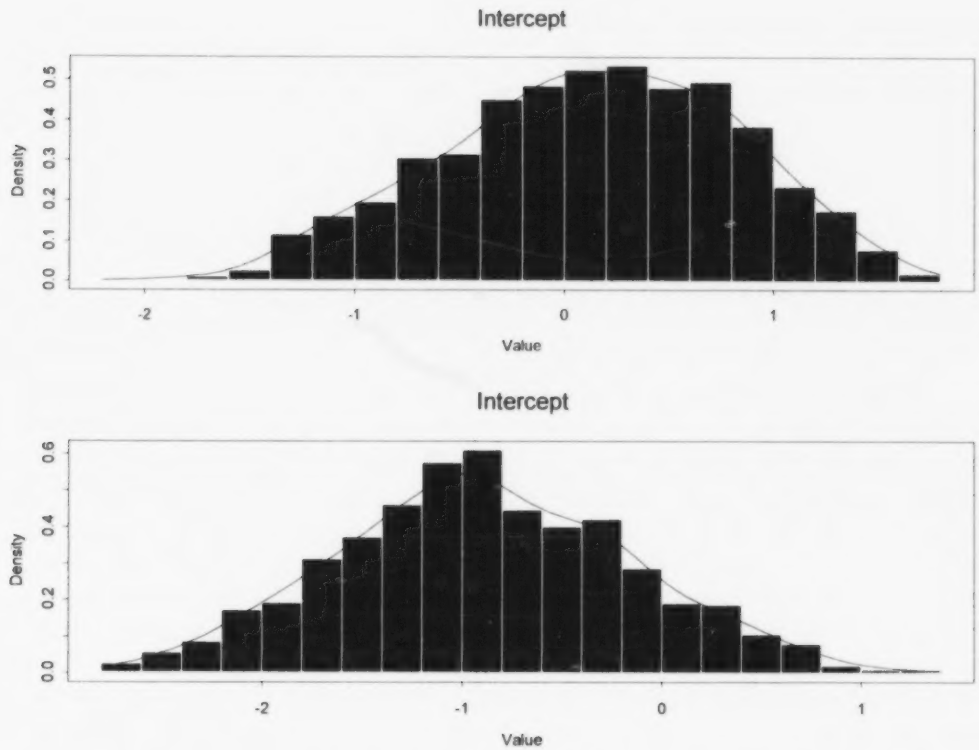

Figure 10. Distribution of boot-strapped estimates of Y-intercept values for DIDSON vs. visual and visual vs. DIDSON regressions in Figure 8, based on 1000 replicates. The top histogram assumes that all of the error is in the DIDSON counts and the bottom histogram assumes that all the error is in the visual counts. The solid vertical lines indicate the observed intercept values for the original data, and the dotted vertical lines indicate the means of the replicates. The difference between these two lines is the estimated bias.

4.3 Comparison of DIDSON counts between observers

The data sets that were counted by multiple observers (Table 2) contained net upstream passage rates ranging from 0 to approximately 8,000 fish per hour. Based on the average percent error (APE), repeated independent counts of the DIDSON data sets would be expected to produce the same count 94% of the time (6% APE) for the net upstream travelling fish. The average error between observers (CV) was 8.4%.

4.4 Sub-sampling analysis

The data used for the temporal expansion analysis included 321 sampled hours (20 minute sub-samples) collected between September 16 and September 29, 2005. Point estimates of cumulative net upstream passage from the first 10 minutes, second 10 minutes and the full 20 minutes do not differ significantly (Figure 11). Net upstream fish passage estimated from the first 10 minutes had slightly wider 95% confidence limits (CIs) than the second 10 minutes and that the full 20 minute data sets displayed even smaller CIs. The difference between the first and second 10 minute CIs are likely due to chance as we would expect them to be the same if the fish behaviour is random throughout the hour.

Although the entire hour of passage can be recorded and counted, this approach is inefficient. In this section we present some of the results of time series analysis (Lilja et al, in prep.) designed to identify an appropriate sub-sampling strategy using the width of the 95% confidence interval for estimated escapement as our performance measure. Figure 12 presents the calculated confidence interval widths based on the same data sets. The solid black line represents confidence intervals when the counts from the first 10 minutes are used and the dashed line represents the confidence intervals when the second 10 minutes are used. We assumed that if the full hour is counted, then the error from this source is zero. Uncertainty around escapement estimates declines exponentially as sub-sample size increases to 10 minutes per hour. Beyond 10 minutes, there is a much slower exponential decline in the width of the confidence intervals. For example, the plot shows that the error is approximately ±5% when using 20 minutes of data out of the hour and about ±10% when using 10 minutes out of the hour. This source of error was then factored into the CIs of the total population estimate as discussed in Section 4.1.

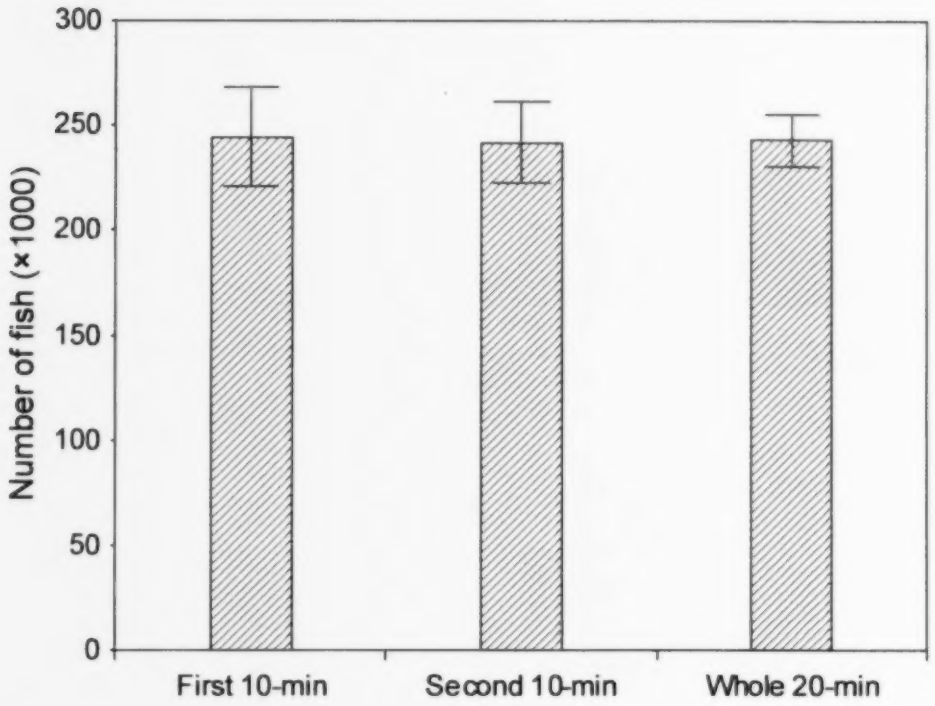

Figure 11. Estimates of the net upstream sockeye salmon for the selected data sets showing the effects of temporal sub-sampling. The first bar displays the net upstream number of fish estimated using the first 10 minutes of the twenty minute data sets, the second bar displays the second 10 minutes and the final bar displays the complete 20 minute data sets. The 95% confidence limits are also included for each condition.

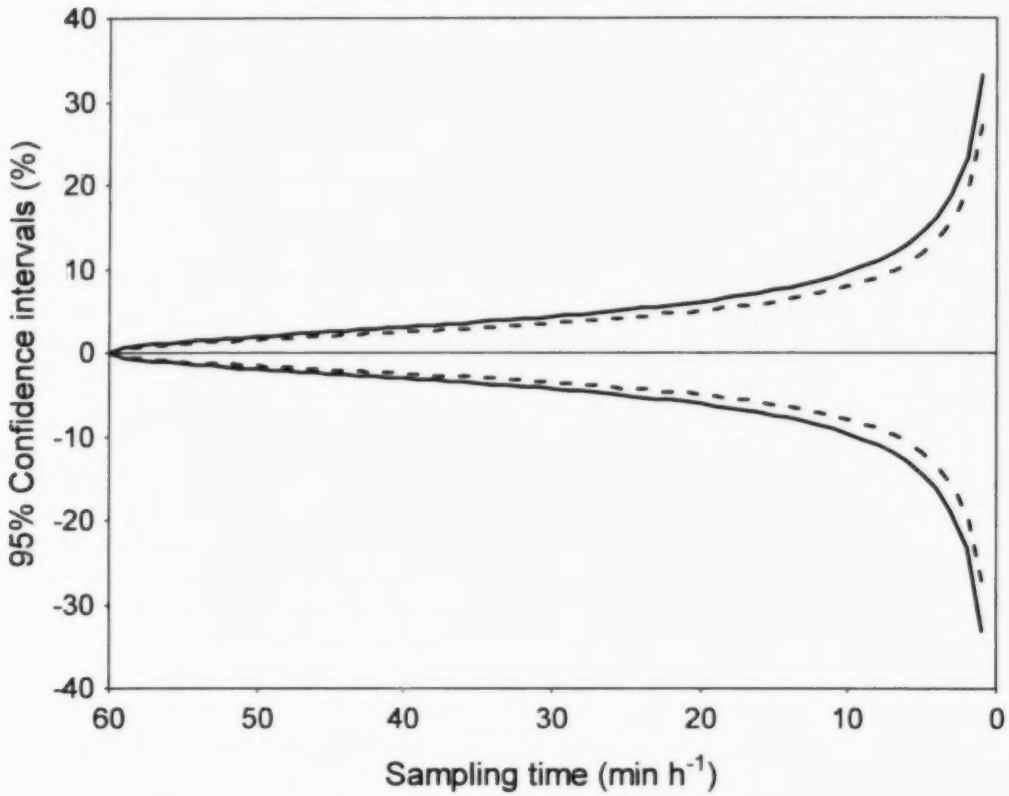

Figure 12. The relationship between the length of time sampled and the resulting 95% confidence limits in per cent for temporal sub-sampling. The solid black line represents confidence intervals when the counts from the first 10 minutes are used and the dashed line represents the confidence intervals when the second 10 minutes are used.

4.5 Fish length measurements

Figure 13 presents the histograms of the measured distributions of fork-length as measured with the DIDSON system within the 1 to 6 m range and those measured manually at the time of tagging. The two samples are normally distributed with a single mode corresponding to the mean. Fish lengths measured from the DIDSON system were, on average, about 1.6 cm greater than those measured by the tagging crew, with means of 59.6 cm (± 3.3 SD) and 58.0 cm (± 2.7 SD) respectively. These means were significantly different (two-tailed t-test, t = -22.695 ; df = 4729.624 ; p = 0).

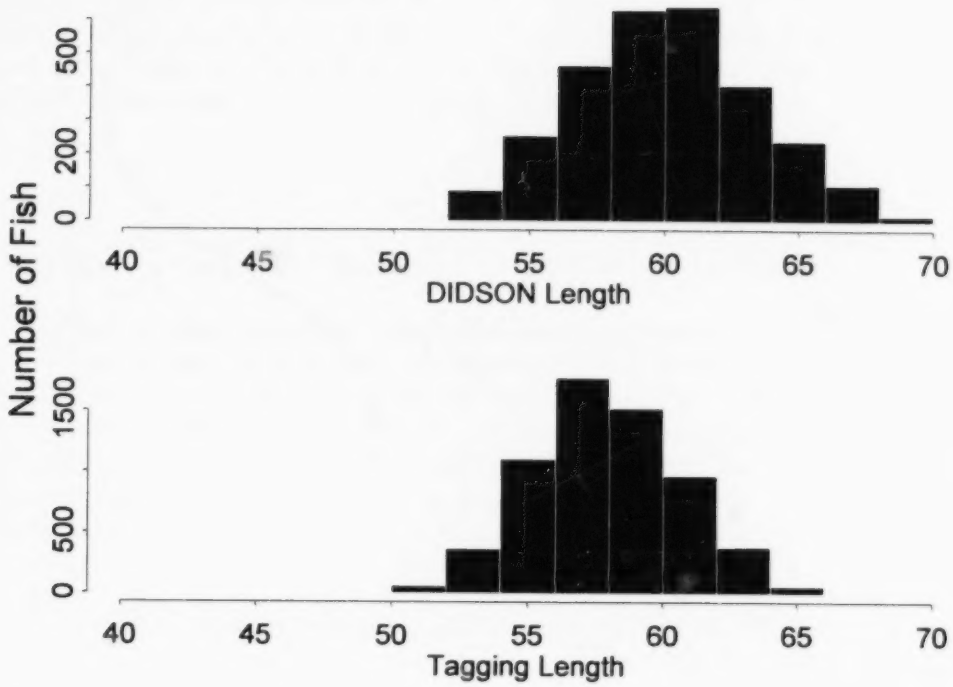

Figure 13. Histograms of sockeye salmon fork-lengths measured with a DIDSON system (top) and measured manually at the time of tagging (bottom). DIDSON sample size, N = 2,874 and the tagging sample size, N = 6,260.

Figure 14 presents two plots that display the character of the sockeye salmon fork-length measurements from (a) the DIDSON sample and (b) the tagged sample. The DIDSON length data were collected in 2 cm length increments, so that the distribution of lengths appears to be discontinuous. In contrast, fork lengths of tagged fish show a smooth, continuous distribution over the range of lengths measured. The differences in the appearance of these data are related to the resolution of the two measuring methods and are discussed in more detail in section 5.5.

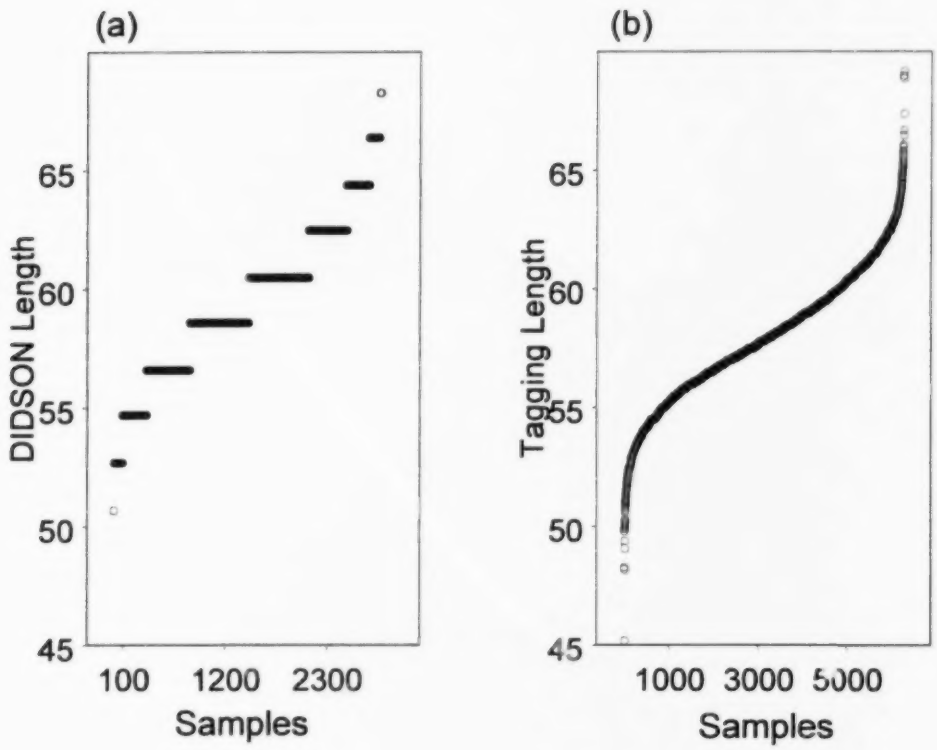

Figure 14. Distributions of lengths sorted into ascending size as measured by the DIDSON system (a), and measured manually at the time of tagging (b), showing the characteristics of the respective samples. DIDSON sample size, N = 2,874 and the tagging sample size, N = 6,260.

4.6 Training of Personnel

One of the objectives of the Horsefly project was to train DFO personnel in the set-up and operation of the DIDSON acoustic system to allow the transfer of knowledge so that others can operate the technology independently. Personnel that were involved with learning the operation of the DIDSON were familiar with the set-up and operation of weir type field projects and so that aspect of the DIDSON project was familiar to them. Therefore, the training was focused on the acoustic aspects of operating this type of enumeration project. We found that personnel with good computer skills could quickly become comfortable with the DIDSON operation and data analyses. To develop the skill level to a point where a person can act as a project leader, we feel that they need to work on an active DIDSON project for one season with experienced personnel. To develop personnel to where they can do the required tasks to assist on a DIDSON project takes about one week. In 2005 we trained one person to the level of being able to become a project leader and two personnel obtained a skill level suitable to

working on future projects. With all aspects of hydroacoustics there is ongoing, on the job learning and skill development, even for highly experienced personnel. It is beneficial for personnel working on acoustic projects to gain a basic understanding of general acoustics through training courses and seminars. With this kind of ongoing training they can be adaptable to the rapid advances in acoustic technology.

5.0 DISCUSSION

5.1 Estimate of sockeye salmon population

Total sockeye salmon escapement into the Horsefly River between Aug 06 and Oct 09, 2005 was estimated to be 645,310 ± 90,599 fish, based on counts obtained using the DIDSON system. The relatively narrow confidence interval around this point estimate of escapement reflects variance related to temporal sub-sampling and precision among independent counts of each file. Because the plot of simultaneous visual and DIDSON counts was statistically indistinguishable from the y = x line (Fig. 8), we conclude that our DIDSON counts are not biased by undetected fish passing the acoustic site and we conclude that these counts are as accurate as fence counts (see Holmes et al., 2006). An alternative interpretation of these data (Fig. 8) is that the magnitude and direction of bias is identical in both the visual and DIDSON counts. We do not accept this explanation because if it were true, then the data used to calibrate the DIDSON counts against enumeration fence counts in 2004 (see Holmes et al., 2006) would exhibit the same bias. The collection and analysis of these visual-DIDSON count data is an important quality assurance procedure and we recommended that this approach be implemented at all future DIDSON acoustic sites where possible.

Based on our experience at the Horsefly River in 2005, we feel that the upstream and downstream travel can be sufficiently well differentiated in the DIDSON files, and simply subtracting the downstream counts from the upstream counts achieves the least biased estimate of the migrating population. We found that some downstream travelling fish were moving extremely fast at the Horsefly site, giving only brief glimpses of the fish (e.g., fish image in 1 or 2 frames only), and we often detected only the acoustic shadow of the fish rather than the fish itself. However, the size and shape of the shadow provided sufficient visual cues to allow detection and counting.

Acoustic sites that have a low incidence of milling behaviour among migrating fish are desirable for accurate estimates of the populations to be made (Enzenhofer and Cronkite, 2000). With the DIDSON sonar this problem is more manageable than with other types of acoustic systems due to the visual nature of the DIDSON data that allows an observer to enhance the image, slow down the movement, and then determine the sequence of events. The proportion of

downstream travelling fish was problematic periodically for DIDSON counts on the Horsefly River. Often one or two downstream fish triggered a large proportion of the upstream fish to turn and head downstream. This problem was much reduced through the highest migration times, which makes counting these high passage rate data sets easier. We felt that the downstream behaviour was manageable with the DIDSON system on the Horsefly River, causing minimal error in the counts (Figure 8) as measured by the high precision among individual observers. The DIDSON acoustic site on the Horsefly River would not be suitable for other types of sonar such as a split-beam system.

Although we attempted to locate acoustic sites below all known spawning, this was not possible for the Horsefly River. An October 07 float/walking survey derived an estimate of 2,024 sockeye salmon below the weir (Jason Wiebe, pers. comm.). By convention, an expansion factor of 1.8 was applied to account for the observability of the fish, resulting in an estimate of 3,643 sockeye salmon spawning below the DIDSON site. This estimate could be added to the population estimate from the DIDSON to derive a total population for the whole river, but the sampling error of the survey is unknown and so we did not do so.

The DIDSON system does not provide information on the vertical distribution of fish unless the system is rotated 90° so that the wide axis is pointing in the vertical direction. We did not feel that a measure of vertical distribution was needed at the Horsefly site because the water was only 0.75 m deep at the thalweg for most of the season and the beams as deployed were ensonifying the entire water column throughout the range. The shallow water depth caused the fish to be bottom oriented, which we confirmed by visual observations. We did not note any vertical stacking of migrating sockeye salmon at this site over the observed range of passage rates (<10 to approximately 8000 fish per hour). There were rare occasions in which two fish travelled one above the other, but they were easily distinguished as separate individuals by the independent movement of the two fish in the horizontal and range dimensions.

There is a possibility that the tagging operations 100m downstream of the DIDSON site were affecting the early season migration behaviour of sockeye salmon by holding back fish during the day. Tagging operations generally ran from 09:00 to 15:00, similar to the low migration times noted from approximately August 25 to September 05 (Figure 6). Prior to August 25, the low migration period seemed correlated with daylight periods, which represented a much longer portion of the day than the tagging operations utilised. An alternate hypothesis is that the behaviour of sockeye salmon we observed is typical of the early season migration period in the Horsefly River. If this hypothesis is true, then more representative tagging could be achieved by offsetting the tagging times earlier or later in the day, as was attempted by the tagging crew for a few days in 2005.

5.2 DIDSON counts compared to visual counts

In Figure 8, both of the regression lines are congruent with the one-to-one line, indicating that the true relationship is 1:1. Based on this finding we conclude that the DIDSON data are not biased as a result of fish moving through acoustic blind zones. Since we used the aiming protocol described in Holmes et al. (2006) we infer that the count data produced from the DIDSON system at the Horsefly River should be as accurate as count data derived from an enumeration fence. Holmes et al, 2006 documented similar results at the Stellako River weir indicating that a properly aimed DIDSON can achieve counts as accurate as those obtained from a weir on a clear water river system. An alternative interpretation of the results in Figure 8 is that both the visual and DIDSON counts exhibit the same bias in terms of direction and magnitude. However, if this interpretation is correct, then similar results reported during calibration of DIDSON counts (Holmes et al. 2006) would mean that enumeration fence counts exhibit the same bias. We do not believe that the Horsefly data are biased because Holmes et al, 2006 showed evidence of systematic bias in the data when viewing conditions were sub-optimal on the Chilko River. Fewer fish were counted visually than were counted with the DIDSON at low passage rates as a result of turbulence and glare and more fish were counted visually than the DIDSON at higher passage rates. Viewing conditions at the Horsefly River acoustic site during visual counts had minimal impact on the counts, because the configuration of the equipment minimised effects related to variable levels of glare. We recommend that future applications of the DIDSON system for salmon escapement estimation continue the practice of compiling and comparing simultaneous visual and DIDSON counts of fish where possible. This testing is important for monitoring the performance of the acoustic system and quality assuring the accuracy of the resulting count data. Changes in bias levels may indicate conditions such as malfunction of the acoustic system, incorrect aim, or changes in the nature of the river that may cause fish to pass the site undetected.

On September 18th we began to note increases in moribund fish drifting downstream past the acoustic site during our visual counts. We concluded that these fish were post-spawners that would have previously been accounted for in the net upstream count. To avoid negatively biasing subsequent daily escapement estimates, we recorded the numbers of downstream moribund fish during our visual counts. These data allowed us to calculate the proportion of moribund fish in the downstream counts and then adjust the daily net upstream count for these previously counted sockeye salmon. Applying this correction to the later season migrants did not greatly increase the overall population estimate as the sockeye salmon numbers were low during this portion of the season, but it did have a strong effect on the daily passage estimates, at times adjusting the daily passage from a negative net upstream count to a positive net upstream count. We feel that it is important to continue to perform visual counts as part of a daily routine of quality assurance/quality control testing of the performance of the

DIDSON system and because we do not yet have reliable and robust methods for acoustically identifying downstream moribund post-spawning fish.

In turbid rivers where visual comparisons are not possible, it is necessary to be extra vigilant in determining that all areas of fish passage are covered by the DIDSON sound beam. This can be done with targets that are of a similar size to the type of fish that are to be detected. If the operators are then certain that all areas of passage are being monitored based on target work, then it can be assumed that the counting accuracy achieved is equal to that measured by Holmes et al. (2006) and to that presented in this report.

5.3 Comparison of DIDSON counts between observers

Comparing DIDSON counts between observers (precision) is necessary and should be maintained as part of the standard approach to quality control for obtaining DIDSON measured population estimates in clear water river systems. A disagreement between observers of more than 20 to 30% should be used to flag the file for a detailed review to determine why such a large error occurred. Large differences between observers counting the Horsefly River files were infrequent, but could be attributed to fatigue, interruptions during the counting process or failure to reset the hand operated mechanical counter (tally whacker). Using this quality control flag, we found an unreliable tally whacker that was causing large differences in counts of the same files and as a result, the counter was removed from duty, and the affected data sets re-counted. Performance monitoring of new personnel as part of their training is an additional important reason for implementing and following the practice of multiple counting of the files. Differences between new and experienced personnel can provide insight into the training programme and the rate of progress of new individuals.

5.4 Sub-sampling analysis

Although a complete census of sockeye salmon escapement past the DIDSON site could be made, implementing a temporal sampling scheme is a more efficient and effective use of limited assessment resources. However, sampling only a fraction of an hour necessarily involves tradeoffs in the level of uncertainty around the resulting estimates of upstream passage and the sampling effort required to achieve these estimates. Because we concluded that fish counts produced from the DIDSON files at the Horsefly River are as accurate as counts of fish moving upstream through an enumeration fence, the remaining variability in the Horsefly River data is related to the sampling effort or differences among independent counts of the same file. Using the width of the 95% confidence interval as a measure of uncertainty in our point estimates of fish passage (Figure 12), we recommend a minimum sample size of 10 minutes per hour to estimate sockeye salmon escapement. Uncertainty in these point

estimates can be reduced approximately 5% if sampling effort is increased to 20 minutes per hour.

Temporal sub-sampling of the DIDSON data to derive the population estimate is useful to reduce the amount of time and effort involved in coming up with manual counts of the data sets. For example, two or three staff can process files from the previous 24 hours in approximately 5 hours. We recommend that an attempt be made to count 20 minutes out of the hour to minimise error and maximise efficiency. If time were available for further counting of the 2005 Horsefly data sets, then we would count the full 20 minute time periods for the high density data sets for which we counted 10 minutes. We believe this would not change the overall point estimate by a significant amount as is shown by the sub-sample in Figure 11, but it would reduce the 95% CI from ±14% to approximately ±10%. If this higher level of accuracy is desired, then counting 20 minutes of every hour is feasible. Another option to minimise the error in the overall population estimate is to count 10 minutes from the hour for the low density data sets and switch to 20 minutes for higher densities. This will minimise the effect of the error on the total estimate.

Sampling and counting more than 20 minutes per hour is not practical when the benefits (narrower confidence interval around the point estimate) are compared with the costs (increased effort to derive the count data) as can be seen in Figure 12. We did not test this hypothesis, but it may be that as the length of time spent counting a data set increases, the accuracy of the count may decrease due to fatigue. Another approach is to have three observers count 20 minute segments from an hour data set, therefore reducing the temporal error to 0%. The error between observers (APE) would still need to be taken into account under this scenario. However, this would require much greater time commitment by personnel to achieve the daily counts, possibly requiring extra personnel, and the large data volume characteristic of the DIDSON data sets would become much more difficult to manage. We do not believe that data sets longer than 20 minutes need to be collected or counted to achieve satisfactory results in most applications of the DIDSON system for sockeye salmon escapement enumeration.

5.5 Fish length measurements

Sockeye salmon lengths measured with the DIDSON system and fork lengths measured manually at the time of tagging differed significantly. There are some factors to be considered when analysing these data in future. We noted that the DIDSON had a moderately coarse resolution for the measured lengths for the data we collected. When a number of fish are measured using either the on-screen 'measure' tool or the 'measure marked fish' tool, the resolution is in steps of approximately 2 cm when a window length of 10 m is used for data

collection. For example, using the 'measure marked fish' function a fish can be measured as 56.6 cm and 58.6 cm but not in between these values.

Measurement resolution in the DIDSON software is coupled to the sample rate when the files are recorded (B. Hanot, Sound Metrics Corporation, pers. comm.), which in turn is a function of the downrange resolution (downrange resolution = Window Length / 512). For example, if the downrange resolution is 2 cm per sample, then the measurement resolution will be 2 cm as well. In theory, measurement resolutions < 1 cm can be achieved when window lengths of < 5 m are used. However, the software will only display data to 1 cm significance. The length data in Figure 14 (a) reflect the 2 cm resolution limit imposed by the use of a 10 m window length. Better resolution of fish length measurements can be achieved by using a 5 m window length for data collection. The 10 m opening between the left and right-bank weirs is the smallest practical opening for this site. Thus, an additional sampling scheme using a 5 m window could be used if higher resolution length measurements were desired.

The two length distributions shown in Figure 13 are normally distributed with a single mode, indicating that the DIDSON was likely sampling the same population as was sampled by the tagging crew. The mean DIDSON length and the mean fork length taken at the tagging site differed by 1.6 cm, with the DIDSON mean length being the larger. Several researchers have documented a positive bias in fish lengths with increasing range related to beam spreading and the fact that a beam sample cannot be partially occupied in the DIDSON system (Xie et al, 2005; Debby Burwen, Alaska Dept. of Fish and Game, pers.comm). However, the difference we documented was smaller than the differences reported by these researchers, likely because we used fish traveling in the first 6 m of range and because we tried to measure the best image on-axis. Several factors are operating in unison to affect length measurements but a complete analysis is beyond the scope of this paper. There is more work to be done on DIDSON measurement bias in the future and these DIDSON measurements may be improved by sampling with a shorter window length.

The bias in the length measurements made with the DIDSON system is due to three things:

1. Uncertainty in what we are actually measuring with the DIDSON system – fork length, total length, or something else;
2. Acoustic beam spreading with range, including the fact that a beam sample cannot be partially occupied by a target; and
3. Decreased image resolution with increased range, which limits measurement resolution.

We recommend that field crews derive empirical corrections for length measurements on-site, by using salmon carcasses or salmon-sized targets of known size held at specified distances from the transducer early in the sockeye

salmon migration period. This would increase the confidence in the DIDSON length measurements of the fish populations.

5.6 Strengths and weaknesses of the DIDSON system for escapement estimation

Riverine sites where the DIDSON system can be used to enumerate sockeye salmon and other species of fish will be constrained by the fact that the maximum window length of detection is 10 m in high frequency mode and 40 m in low frequency mode (Belcher et al, 2001; Sound Metrics Corporation, 2005). We expect that the majority of DIDSON applications in the Fraser River watershed will attempt to use high-frequency mode, but even the low frequency mode will provide better acoustic target recognition and resolution than a split-beam system operating at the same site. Successful enumeration of migrating fish with a DIDSON system depends on the migrating fish exhibiting shore-oriented behaviour, i.e., within 15 m or 40 m of either bank depending on the frequency used, or the installation of structures such as weirs to constrict the migration of fish to the ensonified water volume. Shore-oriented migratory behaviour is typically observed for sockeye salmon migrating through high-velocity environments (Woodey 1984) such as Henry's Bridge on the Chilko River (Holmes at al. 2006) or the mainstem of the Fraser River at Qualark Creek (Enzenhofer et al. 1998). The Horsefly River project demonstrates that when fish are constrained to passing through a weir opening and the passage of fish is visually checked against DIDSON counts, then the resulting data are as accurate as counts of fish through an enumeration fence. This conclusion is consistent with the findings of Holmes et al. (2006), who also hypothesised that DIDSON counts would be accurate at sites in which high water velocities resulted in shore-oriented migratory behaviour in sockeye salmon.

An important benefit of using the DIDSON system to enumerate migrating salmon is that daily estimates of upstream migration can be provided, usually the following day. This timeliness in the delivery of data allows the examination of migration patterns from the beginning to the end of the migration, hourly and diurnal variation in passage rates, and cumulative escapement to a river system. Timely data on cumulative escapement may be useful to fisheries managers to fine-tune adjustments to in-season fisheries to achieve specific escapement goals. A preliminary escapement estimate is therefore available as soon as the migration period ends. The data also allows the accurate plotting of the daily run timing curves in-season.

The portable weir design described by Enzenhofer et al. (2005) performed well on the Horsefly River. The only problem encountered with the weir over the season occurred when an overnight rise in water levels of 35 cm on October 01 washed down several hundred carcasses, damaging some sections of the weir. The carcasses combined with the downstream movement of gravel due to

sockeye salmon spawning directly upstream caused extreme pressure on the lower submerged portion of the weir and resulted in a blow out of one section near the middle of the right-bank weir. Our remedy was to tie the tops of the weir panels back to the walkway structure after removing and reinserting the affected conduit. This small breach in the weir was open for a few hours until repairs were made, so we do not know how many fish may have bypassed the acoustic site undetected. However, we believe that escapement through this opening was minimal because the breach occurred in an area where very few fish attempted to travel upstream and because it occurred very late in the migration period when upstream escapement was typically < 100 per day. Hence, the overall impact on our estimate of total escapement is negligible. In future the tops of the panels will be tied back to the walkway using cinch straps to prevent a recurrence of this problem. It is necessary to be diligent in removing debris from the weir panels of all weir structures, especially during high water events. However, a sudden, unpredictable overnight rise in water level, as we experienced on the Horsefly River, can be problematic.

The Horsefly River project was the first time we used a solar electric system as the primary source of power for the electronic equipment and we found this equipment was well suited to the demands of an acoustic site. We estimated that the DIDSON and the data collection laptop computer could be run for approximately 7 days with average daylight before the batteries were depleted. The biggest power consumers at the site are computer monitors so during times of on-site data analyses when several computers were in operation simultaneously, we used a small generator to maintain the power reserve in our battery bank. Later in the season as the hours of daylight decreased we found that a few hours of charge with the generator running a 40 amp charger were enough to keep the batteries topped up.

Use of a DIDSON system for salmon enumeration in rivers does have a high initial capital cost associated with the purchase of the DIDSON system and required computer and transducer mount. Additionally, the costs of a programme will depend on site specific characteristics such as whether a weir is needed and the proximity to commercial power sources, site access, site upgrades and site maintenance. Excluding the capital costs of the DIDSON system itself, the operational cost of a DIDSON are similar to an average weir type enumeration project where personnel were only required to work during the day. In general, the day to day operation of a DIDSON enumeration project could be handled by 2 to 3 trained personnel for most tasks, especially data processing and analysis. We found that it was advantageous to have 4 or more personnel for short periods during set-up of the system and especially the weirs. If the DIDSON site is in a remote area or secure in a public area, then personnel do not need to be onsite overnight.

The DIDSON system does not provide biological information such as species, sex, state of maturity and age at present. In a clear water river, species

composition can potentially be determined visually, but if the river is turbid, then test fishing will be required. The sockeye salmon in many of the rivers we have assessed for DIDSON enumeration do not exhibit substantial overlap in migration timing with other species such as Chinook salmon, reducing the potential for problems associated with mixed species composition. However, the presence of resident species similar in size to migrating salmon may need to be addressed in some rivers. On the Horsefly River, we estimate that approximately 200 Chinook salmon were enumerated prior to the sockeye season and the only resident species of significant numbers were suckers (*Catostomus* spp.), which were easily distinguished from sockeye salmon by their small size and intermittent locomotive pattern. Test fishing may be necessary if live-samples of the migrating population are required. Sex, age, state of maturity could be assessed periodically by acoustic staff near the acoustic site or alternatively a small crew could be brought in to sample further upstream in a watershed. The latter approach should be taken if spawning success data is required. We note that the weir appears to be a useful sampling tool for carcasses, allowing samples to be taken as soon as post-spawning salmon begin to die.

We found that we needed to make visual counts of the moribund sockeye salmon that were passively moving downstream with the current near the end of the season. This was not difficult to do visually, and was incorporated into the daily visual counts that were done for the purpose of comparing visual counts to the DIDSON counts. In a turbid system, moribund fish (or kelts in the case of multiple spawning populations such as steelhead, *O. mykiss*) may prove more problematic as visual counts would be impossible. On rivers like the Horsefly, the population of salmon sized fish that are capable of spawning more than once is small compared to the large population of sockeye salmon being enumerated (Rob Dolighan, BCF&W, pers. comm.), and therefore the counting error associated with these fish is negligible. In rivers with smaller fish populations, the effect of downstream post-spawners could contribute significantly to the variance in the population estimate. Systems with salmon-sized fish such as steelhead or rainbow trout (*O. mykiss*) that may spawn multiple times over their lifecycle, and migrate downstream after spawning, are yet again another problem, and sampling may be required to determine if the downstream fish have spawned.

5.7 Software Development

We are often asked about automatic counting of the DIDSON files and we have done more work in this area in 2005. We found that the echogram function in the DIDSON software was useful for quickly finding and counting fish at low passage rates where fish events were well separated spatially. For example, we used the echogram function for passage rates up to approximately 40 fish per twenty minute file, but for passage rates higher than 40 fish, it became more time efficient to switch to manual counting during file playback. As the fish passage rate increased, or the distance between the fish decreased, the effectiveness of

the echogram function decreased. The higher the passage rate, the more uncertainty was apparent in the computer algorithm's categorising tracks as upstream or downstream, often categorising them as unknown. As a result, many tracks would have to be looked at individually to determine the direction of travel. Other behaviours such as the high speed of some of the downstream moving fish and the reduced intensity of images at ranges beyond 5 m were also problematic for the DIDSON counting algorithm. The high speed of downstream fish caused them to be in the DIDSON field of view for only one or two frames. This was detectable with the human eye but both the DIDSON and our own computer based counters could not detect this movement. Images of fish at longer ranges were fairly faint, again being readily detected by the human eye, but often not detected by the computer algorithms.

In 2004 we worked with Pacific Eumetrics to develop the first phase (improved image analysis) of a counting aid for the DIDSON system (Cronkite et al., 2005). This software was successful in that routines were developed to increase the contrast of the DIDSON fish images and then track these enhanced images using the Alpha-Beta tracker previously used for split-beam data analyses (Blackman 1986). In its current state the software is effective at creating a strong contrast between the fish target and the background (this is the first step required to develop an automatic counter). The tracking works well on these resulting images, but only at lower passage rates. We have been working with these same types of density related tracking problems in split-beam acoustics as well. Tracking fish movement is not a trivial matter because complex fish behaviours are often unpredictable, and gaps in the acoustic data sets due to the loss of signal are common. Also, the large number of individual targets to be identified and tracked simultaneously is logistically challenging. The software created is called Hydra (Cronkite et al, 2005) which is a tool to aid in the counting of fish in the DIDSON files that allows the user to click on a fish image as it passes through the field of view, adding it to a running total. However, as the passage rates increase, the ability of the automatic tracker to follow a track and the observer to click on the fish images degrades due to the number of concurrent fish images on the screen. If each selected fish image is visually removed from the screen image but continued to be tracked in the background, then the clutter in the image might be reduced enough to allow higher densities to be counted than are currently possible with this tool. We plan to test this idea by implementing this into the software. Compounding problems include rapid downstream movement of fish, gaps in the acoustic data due to temporary loss of the acoustic signal, and the data collection laptop's temporary failure to write to disc because of competing computer processes.

Automatic counting and tools to aid in manual counting are both works in progress and are difficult and time consuming problems because we are attempting to program a computer to track and interpolate moving objects in a manner sim..ar to the human eye and brain. Manual counting is simple and effective and should be continued so that wider use of the DIDSON for

enumeration is not hampered by the current lack of effective automatic counting techniques. Manual counting has proven accurate, precise and simple for field personnel to learn and accomplish. Automatic counting can be implemented later into operating projects if it develops to the point of being useful.

We believe that DIDSON sonar estimation of adult salmon on the Horsefly River proved to be an accurate and cost effective method of obtaining escapement estimates for management purposes. We also believe that enumeration in other rivers could benefit from this technology where the site characteristics are amenable, as the DIDSON system has a greater ease of use, and therefore a greater ease of training new users, than other acoustic systems we have worked with to date.

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Table 1. DIDSON and Visual count data sets used for assessing DIDSON count accuracy.

Date	Time	Count Duration	Visibility Rating	DIDSON Upstream	DIDSON Downstream	Visual Upstream	Visual Downstream	DIDSON Net Upstream	Visual Net Upstream
Aug-28	0800	20	good	9	1	10	2	8	8
Aug-28	1000	20	good	27	6	26	5	21	21
Aug-29	0800	20	good	36	34	35	33	2	2
Aug-30	0900	20	poor/fair	18	0	18	0	18	18
Aug-31	0800	20	poor/fair	15	7	12	1	8	11
Aug-31	0900	20	poor/fair	52	33	52	28	19	24
Aug-31	1000	20	fair	169	49	174	45	120	129
Aug-31	1100	20	fair	112	54	116	51	58	65
Sep-01	1500	20	fair	119	25	117	24	94	93
Sep-02	0900	20	good	54	33	57	39	21	18
Sep-03	0900	20	fair/good	48	31	47	30	17	17
Sep-04	0800	20	fair/good	50	11	49	11	39	38
Sep-04	0900	20	fair/good	40	34	40	37	6	3
Sep-05	0900	20	fair/good	147	42	153	48	105	105
Sep-06	0900	20	fair	176	12	179	11	164	168
Sep-06	1000	20	good	35	17	35	15	18	20
Sep-07	0900	20	fair	104	31	111	26	73	85
Sep-08	0900	20	fair	225	66	225	63	159	162
Sep-08	1100	20	fair	380	130	382	119	250	263
Sep-09	0900	20	poor/fair	215	51	192	43	164	149
Sep-09	1000	20	fair	162	64	161	60	98	101
Sep-09	1300	10	fair	176	36	169	29	140	140
Sep-09	1400	10	poor/fair	340	86	363	28	254	335
Sep-10	1300	10	fair	538	57	481	82	481	399
Sep-10	1400	10	fair	308	24	278	10	284	268
Sep-10	1500	10	fair	461	3	422	2	458	420
Sep-13	1000	10	fair/good	205	25	185	28	180	157
Sep-13	1200	10	fair/good	286	42	306	39	244	267
Sep-13	1300	10	fair/good	140	20	141	22	120	119
Sep-13	1500	10	fair/good	619	67	505	41	552	464
Sep-13	1600	10	fair/good	1313	91	937	77	1222	860
Sep-14	1000	10	good	141	26	174	58	115	116
Sep-14	1100	10	good	251	80	209	96	171	113
Sep-14	1300	10	good	470	105	426	117	365	309
Sep-14	1400	10	good	501	59	444	54	442	390
Sep-15	1100	10	good	155	15	141	26	140	115
Sep-15	1400	10	good	231	35	230	28	196	202
Sep-15	1500	10	good	262	21	248	23	241	225
Sep-16	0900	20	fair	236	21	186	26	215	160
Sep-16	1000	20	fair	257	35	227	34	222	193
Sep-16	1100	20	fair	387	52	357	46	335	311
Sep-16	1200	20	fair	422	70	418	67	352	351
Sep-16	1300	20	fair	342	55	304	43	287	261
Sep-16	1400	20	fair	218	44	203	56	174	147
Sep-16	1500	20	fair	503	98	485	110	405	375

Date	Time	Count Duration	Visibility Rating	DIDSON Upstream	DIDSON Downstream	Visual Upstream	Visual Downstream	DIDSON Net Upstream	Visual Net Upstream
Sep-17	0900	20	fair	594	34	571	36	560	535
Sep-17	1100	20	good	380	39	406	54	341	352
Sep-17	1200	20	good	265	48	253	54	217	199
Sep-17	1300	20	good	374	54	360	49	320	311
Sep-17	1500	20	fair/good	336	53	312	49	283	263
Sep-18	0900	20	fair	422	40	400	39	382	361
Sep-18	1100	20	good	520	46	519	47	474	472
Sep-18	1200	20	fair	567	43	554	54	524	500
Sep-18	1300	20	good	355	24	351	45	331	306
Sep-18	1400	20	good	255	38	252	36	217	216
Sep-19	0900	20	fair	442	34	470	33	408	437
Sep-19	1100	20	poor/fair	273	32	263	31	241	232
Sep-19	1200	20	poor	377	26	361	30	351	331
Sep-19	1400	20	poor	274	31	241	42	243	199
Sep-19	1500	20	poor/fair	313	16	323	23	297	300
Sep-20	0900	20	fair	217	19	226	26	198	200
Sep-20	1100	20	good	246	20	234	24	226	210
Sep-20	1300	20	poor	277	29	231	18	248	213
Sep-20	1400	20	fair	377	24	287	15	353	272
Sep-20	1500	20	good	346	31	291	27	315	264
Sep-21	0900	20	fair	268	36	236	20	232	216
Sep-21	1000	20	fair	222	29	190	22	193	168
Sep-22	1000	20	fair	179	39	110	15	140	95
Sep-22	1300	20	fair/good	274	18	276	18	256	258
Sep-22	1400	20	good	298	17	287	17	281	270
Sep-23	0900	20	fair	160	18	160	17	142	143
Sep-23	1000	20	good	155	17	113	9	138	104
Sep-24	0900	20	good	180	8	164	14	172	150
Sep-24	1000	20	good	115	11	109	9	104	100
Sep-25	0900	20	fair/good	200	15	208	12	185	196
Sep-25	1100	20	good	207	16	181	13	191	168
Sep-25	1200	20	fair	142	21	129	20	121	109
Sep-25	1300	20	fair	203	21	212	19	182	193
Sep-25	1400	20	good	286	16	261	14	270	247
Sep-26	0900	20	fair	283	24	262	27	259	235
Sep-26	1200	20	good	222	18	224	19	204	205
Sep-26	1300	20	fair	221	14	207	14	207	193
Sep-26	1400	20	fair	217	19	235	23	198	212
Sep-27	0900	20	fair/good	175	9	164	9	166	155
Sep-27	1100	20	fair	200	20	203	17	180	186
Sep-27	1300	20	good	178	14	196	20	164	176
Sep-27	1400	20	good	332	25	288	15	307	273
Sep-28	0900	20	fair	226	11	187	16	215	171
Sep-28	1000	20	fair	260	8	227	8	252	219
Sep-29	0900	20	poor/fair	189	12	117	12	177	105
Sep-29	1000	20	fair	173	9	158	10	164	148
Sep-29	1200	20	poor/fair	176	10	139	10	166	129
Sep-29	1400	20	poor/fair	171	28	154	24	143	130

Date	Time	Count Duration	Visibility Rating	DIDSON Upstream	DIDSON Downstream	Visual Upstream	Visual Downstream	DIDSON Net Upstream	Visual Net Upstream
Sep-30	0900	20	fair/good	142	25	95	12	117	83
Sep-30	1100	20	fair	96	14	79	4	82	75
Sep-30	1200	20	fair/good	130	12	125	12	118	113
Sep-30	1300	20	good	96	15	81	12	81	69
Sep-30	1400	20	good	120	19	93	14	101	79
Oct-02	1100	20	fair	26	10	26	10	16	16
Oct-03	1200	20	fair	36	15	22	6	21	16
Oct-04	1200	20	good	28	15	17	8	13	9
Oct-06	1100	20	fair/good	32	21	22	16	11	6
Oct-06	1200	20	fair/good	32	19	39	25	13	14
Oct-07	1000	20	good	10	5	6	4	5	2

Table 2. Net upstream fish counts for DIDSON data sets used to assess the repeatability of counts between observers.

Date	Time	File Length (min.)	Observer 1	Observer 2	Observer 3	Observer 4	Mean
15-Aug	2300	10	5	3			4
16-Aug	1400	10	0	0			0
17-Aug	0500	10	2	1			2
19-Aug	0000	10	43	46			45
20-Aug	0000	10	6	5			6
21-Aug	2200	20	142	136			139
23-Aug	2200	20	186	192			189
25-Aug	0500	20	122	121			122
25-Aug	0400	20	175	179			177
25-Aug	0300	20	130	127			129
25-Aug	0200	20	168	175			172
25-Aug	0600	20	97	112			105
25-Aug	1800	10	157	152	131	134	144
26-Aug	0600	20	45	50			48
26-Aug	0700	20	32	40			36
27-Aug	0800	20	134	136			135
27-Aug	0000	20	283	289			286
27-Aug	1800	20	139	151			145
27-Aug	1700	20	399	344	431		391
28-Aug	1800	20	51	64	37		51
28-Aug	1700	20	63	101	196	157	129
29-Aug	2200	20	197	201			199
30-Aug	0800	10	20	18			19
30-Aug	2200	20	478	393	396		422
31-Aug	0800	20	8	8			8
31-Aug	0600	20	-135	-135			-135
31-Aug	1000	20	120	120	132	127	125
31-Aug	1100	20	50	58			54
31-Aug	0900	20	26	19			23
01-Sep	0000	20	95	94			95
01-Sep	0100	20	58	59			59
01-Sep	0200	20	68	71			70
01-Sep	0500	20	45	43			44
01-Sep	0400	20	37	35			36
01-Sep	0300	20	57	63			60
01-Sep	0900	20	-18	-16			-17
01-Sep	0600	20	41	70			56
02-Sep	1600	20	121	120			121
02-Sep	0900	20	23	21			22
03-Sep	0900	20	15	17			16
03-Sep	1800	20	101	75			88
04-Sep	0800	20	39	39			39
04-Sep	1700	20	218	204			211
04-Sep	0900	20	5	6			6

Date	Time	File Length (min.)	Observer 1	Observer 2	Observer 3	Observer 4	Mean
05-Sep	2000	20	506	504	491	503	501
05-Sep	1900	20	561	544	538		548
05-Sep	0900	20	115	104	108		109
05-Sep	1400	20	43	38			41
05-Sep	1600	20	227	320	176		241
06-Sep	0900	20	163	164			164
06-Sep	1800	20	121	131			126
06-Sep	1900	20	444	488			466
06-Sep	1000	20	22	18			20
07-Sep	1800	20	434	474	488		465
07-Sep	0900	20	83	73			78
08-Sep	1700	20	562	563			563
08-Sep	1900	20	259	256			258
08-Sep	0900	20	155	159			157
08-Sep	0400	20	409	423	429		420
08-Sep	1100	20	261	250			256
08-Sep	1300	20	208	231			220
09-Sep	1300	20	70	69			70
09-Sep	0900	20	169	164			167
09-Sep	1400	10	127	132			130
09-Sep	2000	10	295	315			305
09-Sep	1000	20	106	98			102
10-Sep	1200	10	452	445			449
10-Sep	1400	10	278	284			281
10-Sep	1500	10	448	458			453
10-Sep	2300	10	496	525	538		520
10-Sep	1300	10	429	491	480		467
11-Sep	1300	10	836	854			845
11-Sep	1700	10	900	1064	972		979
11-Sep	1600	10	248	152	190		197
12-Sep	2300	10	723	752			738
12-Sep	1600	10	839	946	795		860
12-Sep	1300	10	30	24			27
12-Sep	1500	10	401	404	288		364
12-Sep	1400	10	86	240	186		171
13-Sep	1100	10	345	330	276	267	305
13-Sep	1700	10	1305	916	1124	1352	1174
13-Sep	1800	10	1275	924	987		1062
14-Sep	1300	10	362	368			365
14-Sep	2100	10	641	668			655
14-Sep	1600	10	851	879	818		849
14-Sep	1700	10	894	833			864
14-Sep	1200	10	554	734			644
15-Sep	1500	10	236	246			241
15-Sep	1100	10	143	137			140
15-Sep	1400	10	201	192			197
15-Sep	1800	10	386	425			406
18-Sep	1800	20	739	724			732

Date	Time	File Length (min.)	Observer 1	Observer 2	Observer 3	Observer 4	Mean
19-Sep	0100	20	752	786			769
20-Sep	1400	20	350	355			353
20-Sep	1600	20	530	518			524
21-Sep	1700	20	450	474			462
22-Sep	0400	20	382	368			375
24-Sep	1400	20	268	281			275
26-Sep	0300	20	271	264			268
28-Sep	1000	20	252	243			248
29-Sep	0700	20	178	181			180
30-Sep	0900	20	117	117			117
30-Sep	1000	20	67	70			69
02-Oct	1300	20	30	55			43
04-Oct	0800	20	22	19			21
06-Oct	1200	20	13	20			17